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This is the final report of a phase I exploratory developmetn. It results in a conceptual design for a computerized methodology using Excel spreadsheet software and a Windows graphical user interface. The methodology will produce LCC estimates, comparisons, Pareto analyses and sensitivity studies for use in balancing avionics requirements and LCC. The methodology developed considers the impact of design alternatives, acquisition stretch-outs, quantity reductions, technology insertions, P^3I, and the use of commonality, modularity, multifunctionality and COTS hardware and software in avionics LCC. It uses defaults for non-critical factors; makes Help screens available to aid inputting, and provides mini-tutorials for application clarification.

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Development of an Automated Methodology for Balancing Avionics Requirements and LCC

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October 1995

Final Report for Phase I
SBIR 95-200

Prepared for

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Preface

This report was prepared for the Research and Cost Branch/Cost Analysis Division, Directorate of Cost Analysis of the Aeronautics System Center of the Air Force Materiel Command under procurement instrument number F33657-95-C-2046 issued 19 April 1995. It is the final report for Phase I of a Defense Small Business Innovation Research (SBIR) Program topic number AF95-200. The program was conducted by Eddins-Earles, a small business located in Concord, Massachusetts. The program was directed and monitored by the Air Force Material Command Aeronautical System Center, Development Planning Directorate, Wright-Patterson AFB, Ohio.

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Summary

This is the final report of a SBIR exploratory development into an integrated methodology for balancing avionics suite performance requirements and life cycle costs. The development resulted in a conceptual design for a personal computer program using Excel spreadsheet software and a Windows graphical user interface. The designed program will support Life Cycle Cost (LCC) estimating and analysis during all phases of avionics equipment acquisition and correlate tradeoffs for all levels of hardware and software performance specifications. It uses two Excel workbooks containing worksheets, dialogsheets, chartsheets, pivottables, and databases created, controlled and processed by VBA computer program code. Its equations used will be derived from data available at the ASC Cost/Schedule Data Center, the RAND Electronics Combat Equipment LCC model, the Air Force COCOMOID model, and the Air Force LCCH model applied to the CAIG breakdown of LCC elements. It will produce LCC estimates, LCC comparisons, Pareto analyses, and sensitivity studies. It applies numerous defaults for non-decisive LCC factors. It makes Help screens available to aid user inputting and provides mini-tutorials for applications clarification. It stores LCC estimates and analyses against design baselines.

The LCC estimating and analysis capabilities developed are integrated into a methodology to support Air Force planning, SPOs, and avionic acquisitions. The methodology developed considers the impact of design alternatives, acquisition stretch-outs, quantity reductions, technology insertions, pre-planned product improvements; and the use of commonality, modularity, multifunctionality, and commercial off-the-shelf (COTS) hardware and software on avionics life cycle cost.

1. Introduction

Avionics are the total set of on-board electronic equipments that enable an aircraft to perform its mission(s). These on-board electronics include suites of equipments that perform functions such as flight control, radar navigation, communications, electronic counter-measures, early warning, weapons delivery, reconnaissance, identification of friend or foe, etc.. As shown in figure 1-1, the percentage of aircraft flyaway cost devoted to its avionics segment has been steadily rising. In 1960 avionics represented approximately ten percent of the total aircraft flyaway cost. In the year 2000, the cost of avionics for the F-22 aircraft is expected to be about one-third of the aircraft flyaway cost. [1]

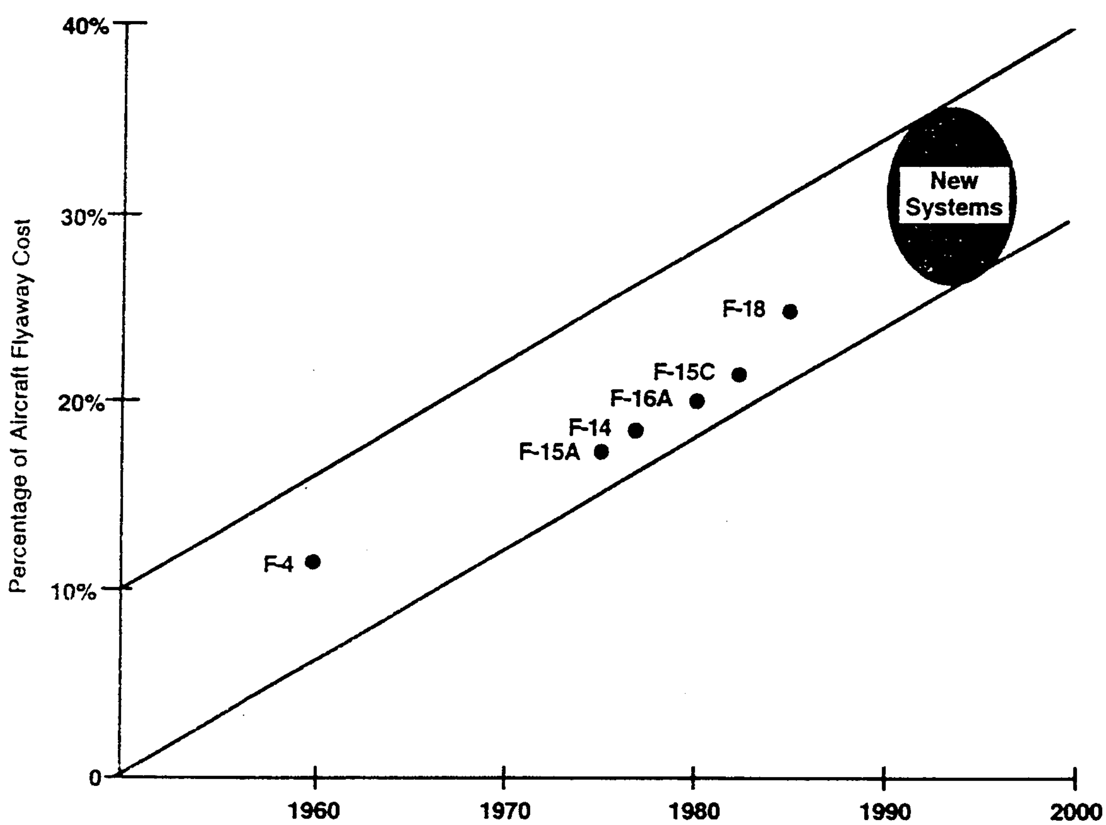


Figure 1-1. Avionics Cost Trends

As avionics sophistication and complexity has grown, operational readiness as a function of reliability, maintainability, retrofit, and reprogram has decreased despite an increase in reliability and computation speed of individual components. In addition, avionics suites are relatively inflexible to changes in mission requirements, require elaborate and costly maintenance and logistic procedures, and because of small lot size, are costly to procure. An automated, integrated design analysis methodology is needed to balance these factors and minimize life cycle cost (LCC), the total cost of acquiring, operating, and supporting avionic equipments over their service life.

Aircraft avionics are generally acquired using the phased development policy outlined in Table 1-1. Three development phases are implemented: Concept Exploration, Demonstration/Validation, and Engineering and Manufacturing Development. During Exploration (CE), overall system requirements are specified (Type A Specs). Specification details are arrived at through trade studies and new technology and risk elements are "breadboard" tested. During Demonstration/Validation (Dem/Val) those system level specifications are finalized and preliminary subsystem or major item development requirements determined (Type B Specs) and "brassboard" models used to test interfaces. During Engineering and Manufacturing Development (EMD) the type B specifications are finalized and preliminary type C (Product), D (Process), and E (Material) requirements identified and Proof of Design (POD) prototype models are built to verify the adequacy of the design technical data package (TDP), and the type C, D, and E specification requirements are finalized and production readiness verified with Proof of Manufacturing (POM) models. All in all three baseline designs are produced: the Functional, Allocated, and Product designs. The final design is validated by both a functional configuration audit (FCA) and physical configuration audit (PCA).

Figure 1-2 illustrates the requirements flow down. In the case of avionics, the system (type A) specification delineates the aircraft performance requirements and a segment (type A) specification delineates avionic performance requirements. System and segment performance requirements are allocated to functional areas which in turn have

performance requirements delineated in type B1 equipment group (avionics suite) specifications. Equipment group performance requirements are allocated to units of equipment which in turn have performance requirements delineated in type B2 specifications and software functional requirement delineated in type B5 specifications.

TABLE 1-1. PHASED DEVELOPMENT POLICY

	DoD 5000.1 PHASES			
	CONCEPT EXPLORATION	DEMONSTRATION/ VALIDATION	ENGINEERING AND MANUFACTURING DEVELOPMENT	
MIL-STD-280 Models	Exploratory Development (Breadboard)	Advanced Development (Brassboard)	Engineering Development (Service Test)	Preproduction (Limited Production)
MIL-STD-490 Specifications	Type A (Prelim Rqmts)	Type A (Final Rqmts) Type B (Prelim Rqmts)	Type B (Final Rqmts) Type C (Prelim Rqmts) Type D (Prelim Rqmts) Type E (Prelim Rqmts)	Type C (Final Rqmts) Type D (Final Rqmts) Type E (Final Rqmts)
Activity In Progress	Breadboard new technology and risk elements (Proof of Concept - Contractor Dedicated) Trade studies using analysis, modeling, test and evaluation (Provides details for Type A Spec) New Technology evaluated for producibility and supportability Plans for reducing production and support risks developed, requirements identified	Additional contractor dedicated model (Proof of System) built; used in tradeoff studies to establish final system rqmts (Type A) & prelim allocated rqmts (Type B) Program critical items and long-lead items identified ILS plan and prelim LSA (all maint levels) rqmts established Production risk reduction projects in work Product design layouts reviewed for producibility and supportability	At least two contractor dedicated models (Proof of Design) built to verify design and evaluated maturity of design thru aggressive analysis, testing, correction and enhancement program. POD matches TDP 100% All mfg deficiencies resolved Program critical and longlead items detailed early for procurement Mfg & Support approve design for producibility and supportability	At least two contractor dedicated models (Proof of Manufacturing) built to verify maturity of Mfg process. Verifies drawing and spec production adequacy, complete planning, production tooling, test equipment, inspection, and ability to meet rate. Creative design ceases, except P^{3}I. Only additional producibility rqmts design allowed Engineering reviews all planning test equipment & tooling design, test plans and procedures for technical adequacy
Prerequisite for Transition	Concept validated by system rqmts review	System requirements validated at system design review	Allocated rqmts validated at CDR and T.E.	Product baseline validated by FCA & PCA. Mfg process maturity validated by production readiness reviews

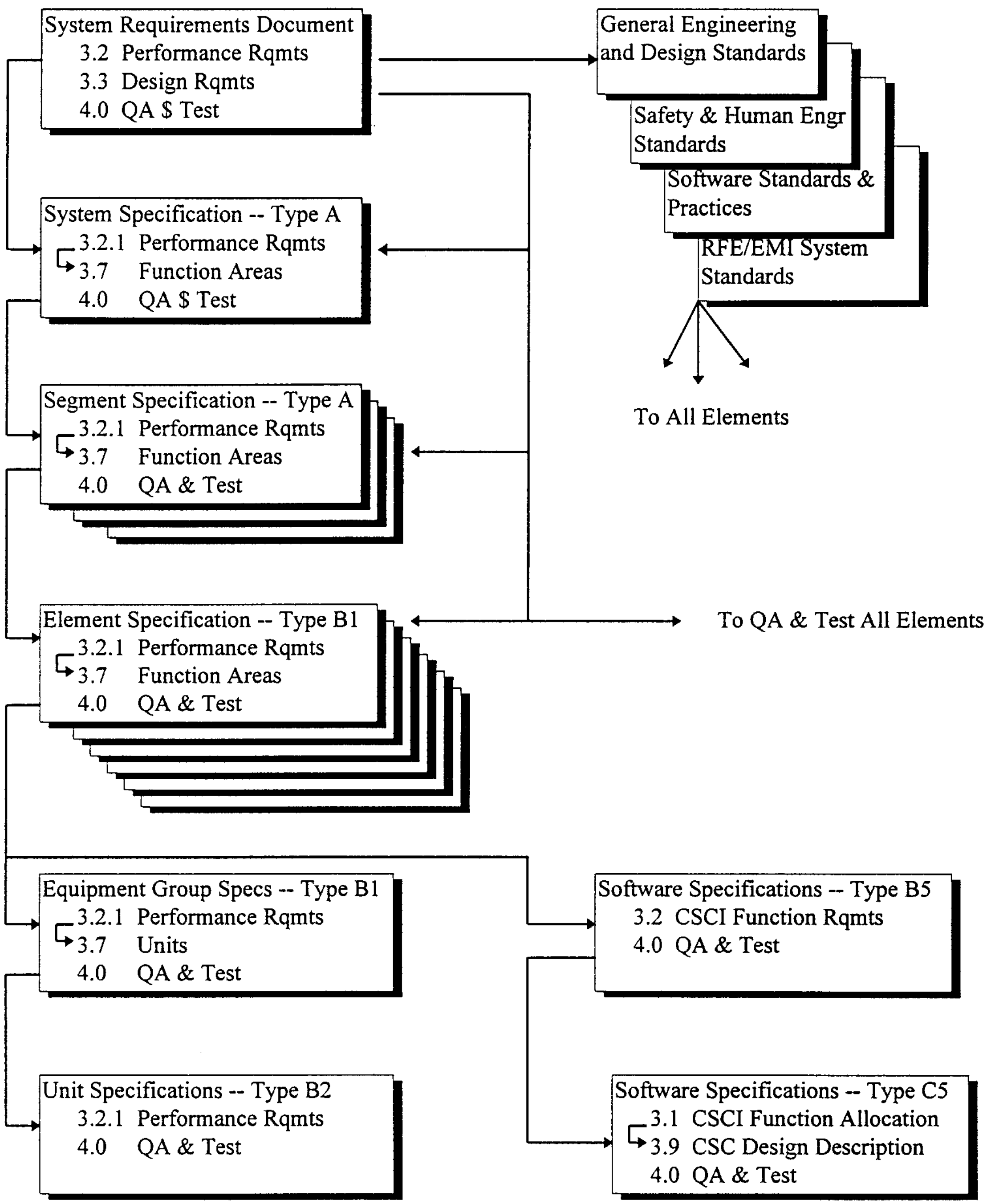


Figure 1-2. Requirements Flowdown in Specifications

At the core of the requirements flowdown is a basic sequence of steps that are iterated: Requirements analysis, Functional analysis, Functional allocation, Alternatives

analysis and trade study, Synthesis, and Evaluation. Each of these steps require inputs from design, production, test, and logistic areas to be integrated and traded for a balanced product. Avionic designs are considered balanced when hardware size, weight, and power requirements are met and hardware and software performance and reliability levels maximized at minimum life cycle cost.

Avionic requirement studies typically tradeoff those characteristics and attributes that are the primary determinants of the military worth of the system and those that are drivers of life cycle cost to arrive at a balanced set of hardware and software requirements. Candidate system configurations capable of satisfying these requirements are then traded off against each other in terms of design characteristics impacting system readiness, performance, reliability, manning requirements, safety, producibility, cost, risk, etc. to arrive at the preferred configuration recommended for development. Currently, separate methodologies are being used in this trade process. In some cases the assessments are done independently by different teams at different locations. This situation sometimes results in misinterpretation and lack of understanding of the interrelationships between performance requirements and life cycle costs as well as the effects key performance parameters have on other performance parameters, design complexity, and LCC.

This report covers an exploratory development into the use of "spreadsheet" type software to formulate an integrated automated approach to the synthesization of life cycle cost-effective and supportable avionics.

2. Tradeoffs

A determination was made of the requirement tradeoffs typically conducted during the different phases of avionics acquisitions. It was based on a review of the cost estimating and risk analysis needs of Air Force System Program Offices (SPOs), Laboratories, and contractors during the electronic design process.

2.1 Concept Exploration

Concept Exploration (CE) is initiated with approval of the Air Force POM. This phase defines and selects avionic concepts for further development. Most activity during this phase is an internal Government responsibility; however, several short-term contracts are usually issued to contractors to define approaches to the mission requirements. The main activities are at the system level. Mission requirements analysis confirms understanding of customer needs and translates these needs into a complete set of mission requirements. Functional analysis and requirements allocation describes the system to be designed as a set of actions and capabilities, and allocates system requirements among those functions to major system segments, among which is the avionics segment. A variety of functional decompositions and trade studies are performed to provide a basis for synthesizing the best combinations of the functional avionic suites and interconnecting architectures at minimum life cycle cost. Data for trade studies are prepared by specialist in each relevant area. Estimates for proposed avionic suites are usually based on extrapolating the performance and cost of existing equipments. The depth of design and cost definition is more detailed for high-risk portions and completely new concepts are generally supported by separate research and development studies. Although only a functional design is developed, a surprising amount of information is determined about maintenance concepts and logistic support needs. A "Use" study identifies the pertinent supportability factors related to the intended use of the new system (mobility, deployment, mission frequency and duration, basing, service life, operational environment, and human capabilities). Reliability, maintainability, and operating and support costs are based on estimates derived from existing items having similar functional and operational requirements.

2.2 Demonstration and Validation

During Concept Demonstration and Validation (Dem/Val) the systems engineering process goes through the same steps as the CE phase, however functional

decomposition and cost estimating is more detailed. Avionics requirements are allocated from avionic suite levels into collections of requirements to the equipment level. The choice among various design implementations is again based on trade studies, this time at the line replaceable unit (LRU) or line replaceable module (LRM) level. LRU designs are generally applicable to three level maintenance, whereas LRM designs generally apply to two level maintenance. Since a major goal of these studies is again to reduce risk, implementations and cost estimates are primarily based on modifications and/or technology upgrades of existing designs. Estimates of size, weight, hardware, interfaces, power and cooling requirements are developed, and based on those estimates, producibility, testability, and manufacturing cost are estimated. Reliability and Maintainability (R&M) requirements are allocated to the LRU or LRM level and a preliminary Failure Mode Analysis is conducted. A more detailed Use study is conducted and logistics recommended hardware and software standardization approaches considered as part of the overall life cycle cost analysis.

2.3 Engineering and Manufacturing Development

During Engineering and Manufacturing Development (EMD) a detailed functional design of circuitry, software and electronic hardware elements, and manufacturing dataset are produced. Schematics are developed that define the circuit logic and major component modules. The end product is the engineering drawings, specifications, and requirements that detail how the LRUs or LRMs are to be built and installed in the aircraft. Required operating and maintenance personnel skill levels are identified along with peculiar support equipment and technical order requirements. Detailed cost estimates are made based on prototype costs, vendor quotes, and production process time standards. Trade studies of alternatives are performed to determine the LRU or LRM hardware and software implementations that best meet requirements at minimum life cycle cost. If the design requires the use of custom application-specific integrated circuits (ASIC), the process is recycled at the microelectronic level.

Tables 2-1 through 2-4 summarize the design activities identified for each of the development phases by a recent Boeing Company study [2]. Table 2-1 shows the design-related tasks performed by Systems Engineering during each of the phases in the DoD acquisition cycle; Table 2-2 shows the design-related tasks performed by Design Engineering during each of the phases; Table 2-3 show the design-related tasks performed by Design Assurance and Logistics support during each of the acquisition phases; and Table 2-4 shows the design-related tasks performed by Packaging and Manufacturing.

Table 2-1. Systems Engineering Design Activities

Concept Exploration	Concept Demonstration and Validation	Engineering and Manufacturing Development
• Prepare system specification and external system interface definitions	• Prepare system/ segment specification and system/segment interface control	• Prepare configuration item specification and hardware and software interface control documents
• System requirements analysis - Derive requirements - Define interfaces	• System/segment requirements analysis - Completeness - Achievability	• LRU requirements analysis - Completeness - Achievability
• System functional analysis	• System/segment functional analysis	• LRU functional analysis
• System requirements allocation - Derive requirements - Define interfaces	• System/segment requirements allocation - Derive requirements - Define interfaces	• LRU requirements allocation - Derive requirements - Define interfaces
• System alternatives generation - Brainstorm - Comparable systems	• System/segment alternatives generation - Brainstorm - Comparable design -Existing solutions - Failure modes analysis	• LRU alternatives generation - Comparable systems - Existing solutions - Failure modes analysis
• System trade studies - Estimated performance - Estimated production time - Estimated design risk - Estimated life cycle cost - Estimated size and complexity - Estimated power and cooling - Estimated weight - Estimated reliability - Estimated maintainability - More detailed design of high-risk portions	• System/segment trade studies - Estimated performance - Estimated functionality - Breadboard studies - Estimated design time - Estimated production time - Estimated design risk - Estimated life cycle cost - Estimated size and complexity - Estimated power and cooling - Estimated weight - Estimated technology availability	• LRU trade studies - Performance estimates - Functionality analysis - Breadboard studies - Schedule estimates - Design risk estimates - Size and weight estimates - Design complexity - Power and cooling estimates - Reliability analysis - Maintainability analysis - Supportability analysis - Life cycle cost analysis - Technology availability studies
• System design synthesis	• System/segment design synthesis	• LRU design synthesis
• System design evaluation - Requirements comparison - Performance estimation	• System/segment design evaluation - Requirements comparison - Performance estimation	• LRU design evaluation - Requirements comparison - Performance analysis

Source: Boeing

Table 2-2. Circuit Design Activities

Concept Exploration	Concept Demonstration and Validation	Engineering and Manufacturing Development
• Assist System Engineering • Concepts • Requirements analysis • Trades	• Assist System Engineering • Requirements analysis • Functional analysis • Function allocation • Alternatives • Trades • Requirements allocation • Interface definition	• Detailed circuit design • Functional analysis • Functional allocation • Interface definition • Alternative generation and analysis • Trade studies • Subfunction analysis • Subfunction interface definition • Circuit alternatives • Circuit trades • Circuit design • Evaluation - Breadboard - Schematic capture - Test procedures - Functional verification - Nominal timing - Critical path analysis - Worst case timing - Loading analysis - Electrical stress - Preliminary layout - Fault isolation - False alarms - Testability • Evaluate and incorporate recommended changes

Source: Boeing

Table 2-3. Design Assurance and Logistics Support Design Activities

Standard for Compliance	Concept Exploration	Concept Demonstration and Validation	Engineering and Manufacturing Development
• Reliability MIL-STD-785B	• Modeling (201)	• Allocations (202) • Failure mode analysis	• Predictions (203) • Parts program (207) • FMEA and FMECA (204) • Failure modes analysis • Reliability critical items (208) • Sneak circuit analysis (205) • Tolerance analysis (206)
• Maintainability MIL-STD-470	• Modeling (201)	• Allocations (202)	• Predictions (203) • FMEA-M (204) • Maintainability design criteria (205)
• Supportability MIL-STD-1388-1A	• Use study (201)	• Use study (201) • Logistics study analysis strategy (101) • Logistics study analysis plan (102) • Mission hardware and software standardization (202) • Comparison analysis (203) • Technical opportunity (204) • Support factors (205) • Functional requirements identification (301) • Support analysis alternatives (302) • Alternative and tradeoff analysis (303)	• Task analysis (401) • Early fielding analysis (402)

Source: Boeing

Table 2-4. Packaging and Manufacturing Design Activities

Concept Exploration	Concept Demonstration and Validation	Engineering and Manufacturing Development
• Support Systems Engineering in concept development • Rough approximations of • System - Size - Weight - Hardware - Interfaces - Power requirements • Line replaceable unit - Size - Weight - Hardware - Interfaces - Partitioning - Power requirements • Boards - Size - Weight - Number of boards - Hardware - Connector input/output - Component placements - Power requirements - Critical circuit - Design constraints • Nuclear hardness and survivability rqmts • Generic parts • Stress & vibration rqmts • Thermal requirement • Read-only memory packaging design cost • Schedule	• Support Systems Engineering in concept development • Estimate and define • System - Size - Weight - Hardware - Interfaces - Power requirements • Line replaceable unit - Size - Weight - Hardware - Interfaces - Partitioning - Power requirements • Boards - Size - Weight - Number of boards - Hardware - Connector input/output - Component placements - Power requirements - Critical circuit - Design constraints • Nuclear hardness and survivability rqmts • Generic parts • Stress & vibration rqmts • Thermal requirement • Firm packaging engineering costs • Schedule • Perform preliminary package analysis • Thermal • Stress and vibration	• Support Design Engineering in line-replaceable unit and board layout and breadboard design • Define and specify - • System - Size - Weight - Hardware - Interfaces - Power requirements • Line replaceable unit - Size - Weight - Hardware - Interfaces - Partitioning - Power requirements • Boards - Size - Weight - Number of boards - Hardware - Connector input/output - Component placements - Power requirements - Critical circuit - Design constraints • Nuclear hardness and survivability rqmts • Detail part numbers • Generic parts • Stress and vibration characteristics • Thermal characteristics • Schedules • Design • System - Envelope - Cabling - Cooling - Hardware • Line replaceable unit - Envelope - Cabling - Cooling - Hardware • Boards - Component placement - Route board components - Generate board fabrication data - Generate numerical control data - Generate drawings

Source: Boeing

3. Available Data

Avionics acquisition contracts contain requirements for deliverable data that will be used in the methodology for balancing avionic requirements and life cycle cost. The deliverable data items that most apply to life cycle cost tradeoffs are from the financial, software, reliability, and logistic support areas:

DI-F-6006 Cost Data Summary Report
DI-F-6007 Functional Cost Items Report
DI-F-6008 Progress Curve Report
DI-F-6009 Plant-Wide Data Report
DI-IPSC-81435 Software Development Plan
DI-R-7082 Reliability Predictions Report
DI-R-7085A Failure Mode, Effects and Criticality Analysis Report
DI-MNTY-80825 Maintainability Modeling Report
DI-MNTY-80826 Maintainability Allocation Report
DI-MNTY-80827 Maintainability Prediction Report
DI-S-7115 Use Study Report
DI-S-7116 Comparative Analysis Report
DI-S-7117 Technology Opportunities Report
DI-ILSS-80114 Logistic Support Analysis Record Data

Much of the data submitted for these data items has been stored at the Air Force ASC Cost/Schedule Data Center or has been abstracted into available Air Force databases.

The Air Force **Aeronautical Systems Center (ASC) Cost/Schedule Data Center** maintains historical information on cost estimates, program reviews, and cost reports. [3,4,5,6,7,8] It is believed that data is available in this center from which Help screens and cost estimating relationships (CERs) for CE, Dem/Val, and EMD phase costs and avionics equipment, installation, and LRU costs can be developed, as well as defaults for

order and ship costs, technical order maintenance costs, inventory management costs, and software maintenance costs.

The **Avionics Planning Baseline** (APB) is a database of avionics information on Active, Reserve, and Air National Guard aircraft. [9] It lists the avionic equipments and architectures employed, along with size, weight, power requirements, and the year of development of each aircraft in the inventory. The categories of avionics information maintained in the database are existing avionics, on-going avionic changes, and planned avionic changes. The Avionics Planning Baseline will serve as the Hardware Breakdown Structure for the methodology to be developed. The grouping of aircraft by Mission (e.g. Cargo, Bomber, Fighter, etc.) and within each mission group by Mission Design Series (e.g. B-52H, F-16A, EC-135A, etc.) used in the APB, and the listing of equipments by function (e.g. Communications, Controls and Displays, etc.) will be used as stored internal databases in the Excel application to be developed to identify Avionic Segments and Suites. The equipments listed in the APB will be used to build the databases from which Help screens will be built.

Air Force **I65-503** is a database of Cost and Planning factors maintained on the Financial Management Analysis Bulletin Board of the in-house computer network of the Aeronautical Systems Center. [10] It contains official US Air Force cost and planning factors that can be used to estimate resource requirements and costs associated with Air Force force structures, missions, and activities. In particular, it pertains to operating and support (O&S) cost estimates for Air Force aircraft. It will be used to develop internal databases for avionics related military specialty code training costs, military and civilian grade level composite pay rates, and installation support costs.

The Air Force **Unified Data Base** (UDB) is maintained by the Air Force Acquisition Logistics Center to provide a historical repository of Logistic Support Analysis Record (LSAR) data on operational systems. [11] It is specifically designed to assist in the establishment of a Baseline Comparison System for use in tradeoff studies,

analyses, and predictions on new aircraft. Hopefully, this database can be used to develop MTBFs, Remove and Replace Times, and MTTRs defaults; LRU and Support Equipment types costs; and LRU weights. If not, the LSARs themselves will be used.

Air Force **Software Metrics Policy** issued 16 February 1994 mandates the collection, analysis, and use of software metrics for all software intensive systems (greater than 20,000 source lines-of-code) and strongly encouraged their use on all systems. [12] Those metrics should yield the data required for building the Help screens needed to support software cost estimating.

The Air Force **Cost Analysis Agency** has been sponsoring an avionics data collection effort that is scheduled to be complete in December 1995. [13] This information will be investigated for possible application within the methodology for balancing requirements and LCC.

The Air Force **Supportability Investment Decision Analysis Center** (SIDAC) maintains a bibliographic database of logistic and supportability information and models that will be researched during phase II for factors, models, and data that can be integrated into the methodology.

Department of Defense Manual DoD 5000.4-M calls for **VAMOS** (Visibility and Management of Operating and Support Costs) program data to be used for cost tradeoffs.[14] Eddins-Earles did not have the opportunity to assess the viability of using that database during phase I of this SBIR. It will, however, be addressed during phase II.

4. LCC Models

There are a great number of LCC models currently used within the USAF, and new models are being developed and old ones constantly adapted to meet the specific needs of a given program or project. Reference 15 gives an excellent review of many of

these models.[15] LCC models based on different estimating methodologies tend to be used during different phases of the weapon system acquisition cycle. When only gross system and equipment characteristics are known and a large number of alternatives are under consideration, models that employ cost estimating relationships (CERs), scaling factors, and analogous system and equipment comparisons are most used. As the design starts to stabilize and more information becomes available, models based on analogous and engineering estimating methods are more frequently used. Air Force LCC models were analyzed for features which could be incorporated into an automated methodology to perform the analysis and trade studies required to balance avionics requirements and life cycle costs. Features from the RAND Electronic Combat Equipment model, Air Force Cost Center factors studies, the Air Force COCOMO and LCCH models, and the CAIG LCC breakdown will be used in the developed methodology.

4.1 Electronic Combat Equipment LCC Model

The RAND Corporation developed an Electronic Combat (EC) Equipment LCC Model to conduct tradeoff analyses to determine the most cost effective combination of EC equipment in support of NATO defense suppression operations.[16] That model covers the estimation of cost of Group B hardware (the EC equipment kits to be installed), and Group A kits (the hardware required to install Group B equipment on an aircraft). It estimates acquisition, installation, and annual operating and support costs. It assumes that acquisition costs can be estimated as a function of Group B hardware cost. It is based on CERs developed from Air Force Reconnaissance/Strike and Electronic Warfare Systems Program Status and Bluebooks stored at the ASC Cost Data Center. Personnel costs were based on Air Force Regulation 173-13 factors (now AFI65-503) applying the assumption that manpower strength varies in proportion to the net increase (or decrease) in the value of EC equipment being supported plus a prorated share of the cost of base operating support and medical support. The replenishment spares and depot maintenance factors used in the model were based on data from other RAND studies.[17,18] It is

believed that many of the models CERs can serve as default CERs in the developed methodology.

4.2 Development Cost Factor Models

Avionics development cost factors and CER models have been developed by analyst using Air Force Cost Center data on the Actual Cost of Work Performed (ACWP) reported as part of the Contractor Cost Schedule Control system.[3,4,5,6] These factors are ratios of supporting activities cost to prime mission equipment (PME) cost. For development and production they include factors for software, system engineering/program management, system test and evaluation, peculiar support equipment, data, and training. They have been developed for different Air Force programs and as composites from several programs. These factors will be integrated into the developed methodology.

4.3 COCOMOID Model

The COCOMOID model is the Air Force version of the COCOMO software cost estimating model. The model and its database projects were originally issued in 1981. Since then the model has gone through two refinements: COCOMO Ada in 1989 and COCOMO 2.0 in 1994. Essentially, the model uses raw counts of size, such as source lines of code (SLOC), functions, objects, and features or various combinations of all three as input. Functions are function points, which are the weighted sums of five different factors that relate to user requirements; objects are weighted sums of screens, reports, and third-generation modules; features are weighted sums of algorithms and logic data files for real time software. The model uses CERs that apply various factors for complexity, reuse, re-engineering, conversion, breakage, and relative economies or diseconomies of scale. Modifiers for the categories of product, personnel, platform, and project are used to adjust person-month estimates derived from the input. The Air Force Cost Center maintains a complete implementation of all COCOMO versions including models for

basic, intermediate, detailed, maintenance and calibration (coefficient) COCOMO, as well as the Ada version. The Air Force version is called COCOMOID and the last release was in 1991. [19] CERs from this version will be integrated into the life cycle cost equations used.

4.4 LCCH Model

Probably the most used Air Force logistics related LCC models are the Logistic Support Cost (LSC) model and a derivative, the LCCH model. [20,21] They are operating and support (O&S) cost estimating models input at the LRU and shop replaceable unit (SRU) level of hardware. They have five main input files:

1. Standard cost factors,
2. Logistic factors,
3. Hardware definition data,
4. Support equipment data, and
5. Contractor data.

The standard cost factor file contains standard labor, shipping and material consumption rates which are needed for model computations. The logistics factors file sets the support scenario for the system being analyzed. Included in this file is information on the operational life of the system, the number of systems that will be deployed and the number of bases where these systems will be located, as well as system operating times and depot and base repair periods. The third file, the hardware definitions file consists of parameters which define and characterize the hardware configurations of the system, such as weight, number of replaceable units and mean time between failures (MTBF). A separate record is required for each maintenance replaceable unit in the system. Support equipment parameters, such as the number of test sets and the cost per set, are included in the support equipment file. The contractor data file consists of related unit acquisition cost, number of new inventory items required and

warranty price. Many of the equations and factors of the LCCH model will be used in the developed methodology.

4.5 CAIG LCC Breakdown

The Cost Analysis Improvement Group (CAIG) of the Department of Defense developed a uniform set of definitions for LCC. [22] Life Cycle Cost is broken into three areas: Research and Development (R&D) Cost, Investment Cost, and Operating and Support (O&S) Cost. R&D costs include the cost of the three development phases: Concept Exploration and Definition, Concept Demonstration and Validation, and Engineering and Manufacturing Development. Investment costs include the costs of production and deployment for the prime equipment and its support. This includes the cost of low rate initial production (LRIP) and rate production (RP), training, data, initial spares, war reserve spares, pre-planned product improvement (P^3I) programs, and military construction. Operating and Support costs include personnel costs, unit level consumption, depot maintenance, sustaining investment, system and inventory management, and indirect O&S costs. Table 4-1 shows the breakdown of the CAIG related LCC elements that will be used in the personal computer program designed for balancing avionics requirements and LCC.

5. Automation Methodology

The methodology developed to support the balancing of avionics requirements and life cycle costs uses an application program developed for a personal computer, the DOS operating system, a Windows 3 graphical user interface, the Excel 5 spreadsheet and object library, and embedded computer code.

Table 4-1. Applicable CAIG LCC Elements

Research and Development	Investment	Operating and Support
Concept Exploration/Definition Phase	Low Rate Initial Production	Mission Personnel Pay & Allowances
Concept Dem/Validation Phase	Prime Mission Equipment	Operations
Prime Mission Equipment	System Engr/Program Management	Maintenance
Breadboard/brassboard Models	Platform Modification	Unit Level Consumption
System & Application Software	Peculiar Support Equipment	Intermediate Maintenance
Test and Evaluation	Training	Depot Maintenance
System Engr/Program Management	Data	Maintenance
Data	Initial Spares & Repair Parts	Replenishment Spares
Engr & Manufacturing Develop Phase	Other	Contractor Support
Prime Mission Equipment	Rate Production	Interim Contractor Support
Prototypes	Prime Mission Equipment	Contractor Logistics Support
System and Application Software	System Engr/Program Management	Sustaining Support
Test and Evaluation	Platform Modification	Inventory Management
System Engr/Program Management	Peculiar Support Equipment	Technical Orders
Peculiar Support Equipment	Training	Support Equipment
Training	Data	Software Maintenance/Support
Data	Initial Spares & Repair Parts	Indirect Support
Other	Other	Personnel Support
		Installation Support

The Excel 5 application designed is a spreadsheet program, that is, an electronic analogue of an accountant's spreadsheet of columns and rows. It has four components: worksheets, charts, dialog boxes, and databases. In Excel a spreadsheet is called a worksheet. The worksheet component displays and analyzes text and numbers in rows and columns; the chart component produces charts; the dialog box component receives user inputs; and the database component manipulates lists of information. Worksheets can be combined into a workbook which can contain up to 255 sheets. Each sheet contains 256 columns and 16,384 rows. Each column can be up to 255 characters wide. In addition, Excel has its own utility programs, and a large number of mathematical and statistical functions, and permits operational automation to be implemented with the Visual Basic for Applications (VBA) programming language.

Excel 5 includes what is called an object model. An object in Excel can be controlled and programmed into a spreadsheet application to accomplish a task. Each object has characteristics, or properties, that control their appearance or behaviors. In addition to properties, objects have actions, or methods, they can do. As shown in figure 5-1, Excel's object model contains 128 different objects, ranging from simple

objects such as textboxes to complicated objects such as pivottables.[23] The application object exists at the top of the Excel hierarchy and represents the environment in which VBA applications are run. The workbook object is contained in the application object and represents an Excel file and serves as the container or delivery mechanism for VBA applications. Automation is accomplished by using VBA. Typically, through VBA, the condition of an object is changed by setting the value of one of the object's properties, or is examined by returning the value of one of the object's properties, or is caused to perform a task it can do by using a method of the object.

The objects used for automation are worksheets, dialogsheets, chartsheets, modules, windows, and their related subobjects (drawing objects, pivottables, range, and scenarios). Worksheets are used to build control forms, databases, and output reports. Dialogsheets are used to enter data and select options. Chartsheets are used to build charts. Modules are used to build reusable VBA code to control data processing, data analysis and report formatting. Pivottables are used to abstract data from databases. Windows objects are used to display split screens. Controls are placed on worksheets, custom built dialogsheets, and chartsheets to make the application flow. VBA code links controls directly to cells on worksheets. The primary controls are Button objects, Check Box objects, Option Buttons and Group Box objects, Scroll Bar and Spinner objects, List Box objects, Drop-Down objects, Edit Box objects, Combination Drop-Down Edit objects, and Combination List-Edit objects.. The Button object is used to provide the user a means to execute a macro (VBA procedure). The Check Box object is used to set options. The Option Button is used to select one of a list of options placed within a Group Box. The Scroll Bar and Spinner objects are used to provide a graphical interface for incrementing a display of values. The List Box object is used to make a selection from a scrollable list of items. The Drop Down object is used in a similar manner as the List Box with the exception that a single text box with an arrow will appear and the scrollable list will appear when the arrow is selected. The Edit Box object is used to execute a macro to enter data provided by the user. The Combination List-Edit Box object is used to make a selection from a list or write over a single text box entry. The

Combination Drop-Down Edit Box object is used to make a selection from a Drop-Down box or to enter user input data.

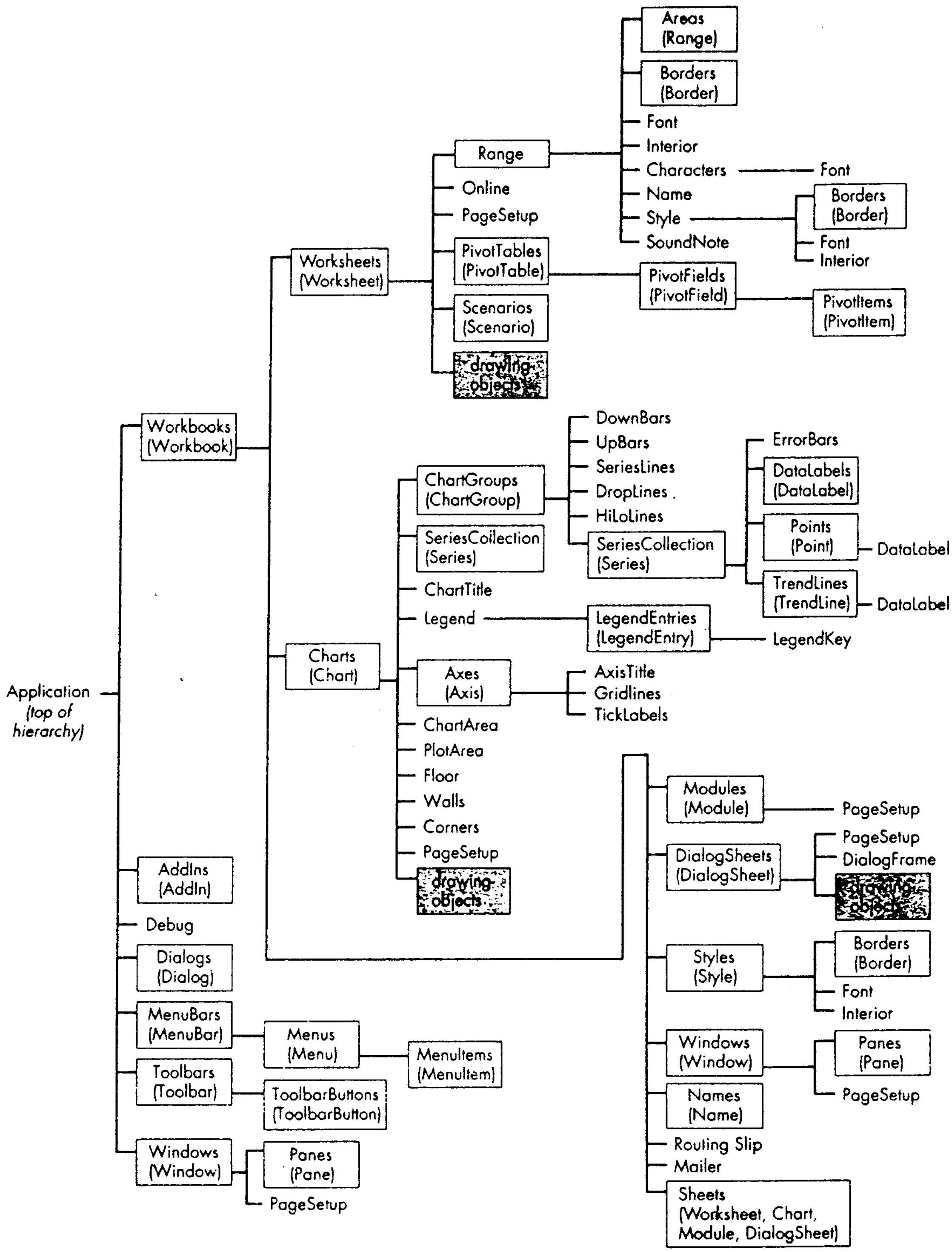


Figure 5-1. The Excel Object Hierarchy.

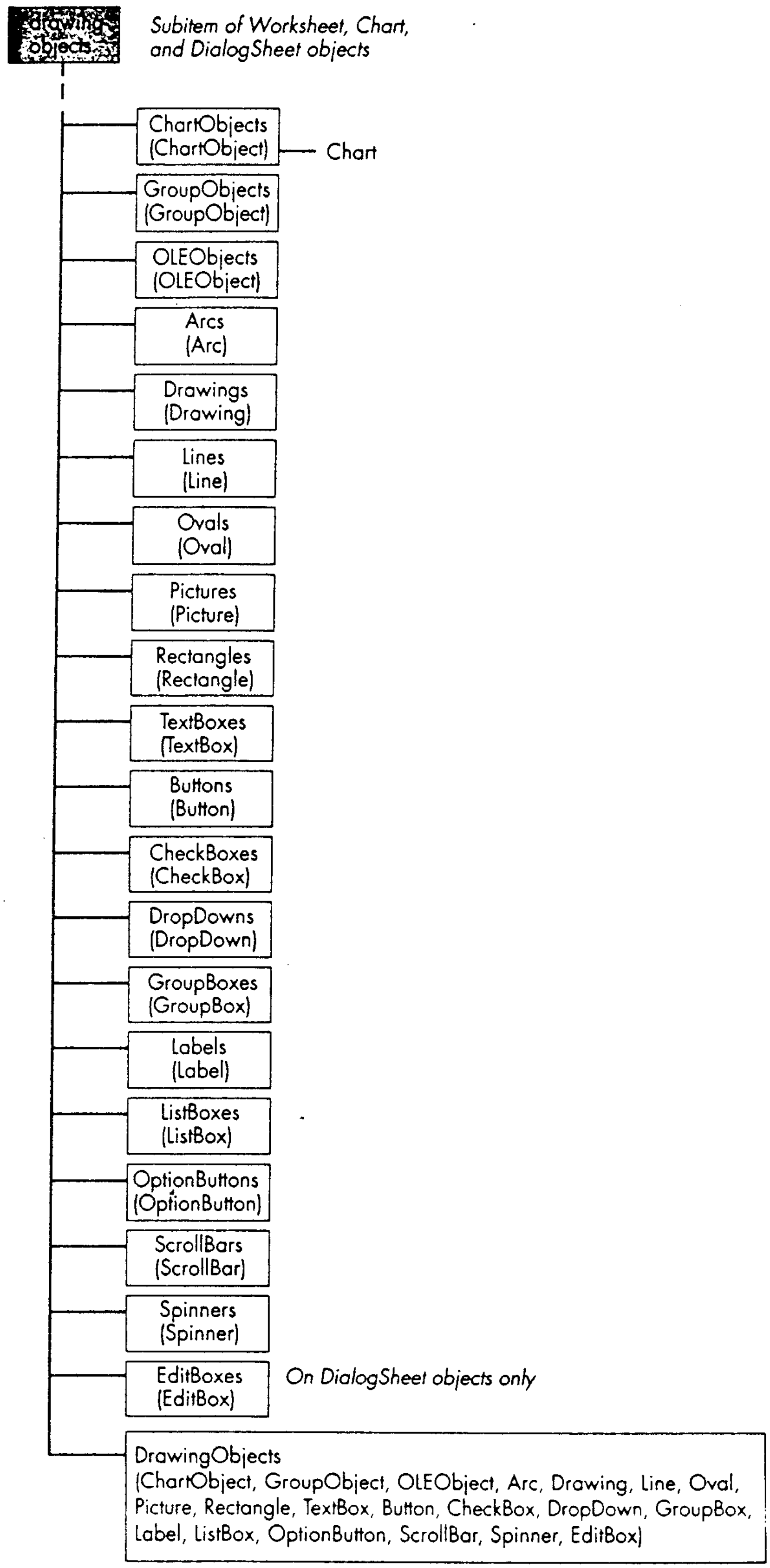


Figure 5-1. The Excel Object Hierarchy (cont'd).

6. Conceptual Design

The methodology designed for balancing avionics requirements and life cycle costs uses an Excel application that estimates the life cycle cost of different design implementations, does LCC comparisons, Pareto analyses, and cost factor sensitivity studies; stores these cost histories against development baseline designs; and permits different design teams to have access to the same model, data, and trade study histories.

The concept uses two workbooks of Excel objects: a LCC Analysis workbook and a Data Exchange workbook (figure 6-1.). The LCC Estimating and Analysis workbook provides the software to estimate life cycle costs for an avionic segment, its suites, equipments, LRUs and/or LRMs, and CSCIs, and performs Pareto analyses, sensitivity studies, and comparative analyses of these estimates. The Data Exchange workbook contains the data and pivottables for Help screens, and storage for LCC estimates and analyses already conducted.

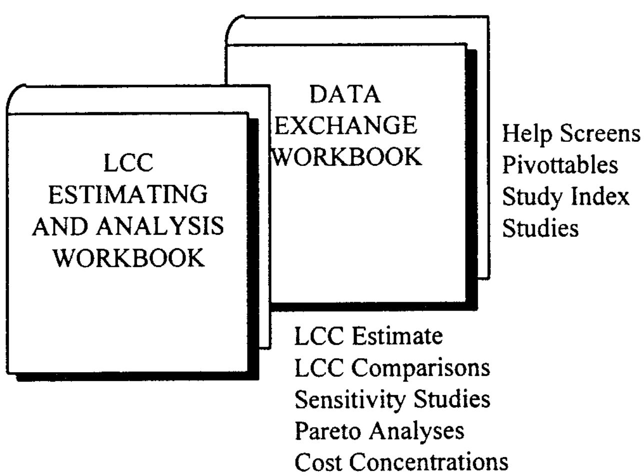


Figure 6-1. Basic Concept.

6.1. LCC Estimating and Analysis Workbook

This Workbook contains the file of computer code and Excel objects that builds the control screens, dialog boxes, output reports, and trade study history indexes used to conduct avionics LCC estimates and analyses. Table 6-1 tabulates the workbook sheets and briefly describes their functions in the Excel application.

Table 6-1. LCC Analysis Workbook

Name of Sheet	Description
Open_Control	Worksheet which contains the start-up screen for the application.
Start and Finish Code	VBA module which starts the application and initializes prior to closing.
Option_Control	Worksheet which presents user with application options.
Option_Code	VBA module which calls up the appropriate screen for option selected.
Level_Control	Worksheet which presents user with avionics levels for analysis.
Level_Code	VBA module which brings up avionic level input dialog.
Develop_Dialog	Dialog sheet for development cost override inputs.
Develop_Code	VBA code for storing development inputs to spreadsheet and call up of specified level dialog.
Segment_Dialog	Dialog sheet for Segment level inputting screen.
Another_Suite_Dialog	Dialog sheet for cycling Segment level inputting screen.
Segment_Code	VBA module which stores Segment inputs to spreadsheet and calls up Suite level input dialogs.
Suite_Dialog	Dialog sheet for Suite level inputting screen.
Another_Equipment_Dialog	Dialog sheet for cycling Suite level inputting screen.
Suite_Code	VBA module which stores Suite inputs to spreadsheet and calls up Equipment level input dialogs.
Equipment_Dialog	Dialog sheet for Equipment level inputting screen.
Another_LRU_Dialog	Dialog sheet for cycling Equipment level inputting screen.
Equipment_Code	VBA module which stores Equipment inputs to spreadsheet and calls up LRU level dialog box.
LRU_Dialog	Dialog sheet for LRU level inputting screen.
LRU_Code	VBA module which stores LRU inputs to spreadsheet and calls up CSCI level dialog box, if applicable.
CSCI_Dialog	Dialog sheet for CSCI inputting screen.
CSCI_Code	VBA module which stores CSCI inputs to spreadsheet and calls up Deployment dialog box.
SRU_Dialog	Dialog sheet for SRU level inputting screen.
SRU_Code	VBA module which stores SRU inputs to spreadsheet and calls up Deployment dialog box.
Deployment_Dialog	Dialog sheet for Deployment inputting screen.
Deployment_Code	VBA module which stores Deployment inputs to spreadsheet and calls up Support dialog box.
Support_Dialog	Dialog sheet for Support inputting screen.
Support_Code	VBA module which stores Support inputs to spreadsheet and calls up Global dialog box.
Global_Dialog	Dialog sheet for Global inputting screen.

Name of Sheet	Description
Global_Code	VBA module which stores Global inputs to spreadsheet and calls up Comparison Decision control screen.
Comparison._Control	Worksheet which presents comparison study decision.
Comparison_Code	VBA module which recycles to call up levels control or presents output view and print screen.
Sensitivity_Dialog	Dialog sheet for sensitivity inputting screen.
Sensitivity_Code	VBA module which stores sensitivity inputs to spreadsheet and calls up Deployment dialog box.
Appl_InstDialog	Dialog sheet for instructions for different types of studies.
Inst_Code	VBA module which calls up Help screens for different Applications.
Baseline_HistoryDialog	Dialog sheet for Baseline History index request inputting.
Baseline_Code	VBA module which activates pivottable search in Data Exchange Workbook and calls up Baseline Index display in view screen.
Segment_Code	VBA module which generates Segment LCC Estimate report.
Suite_Code	VBA module which generates Suite LCC Estimate report.
Equipment_Code	VBA module which generates Equipment LCC Estimate report.
Seg_Com_Code	VBA module which generates Segment LCC Comparison report.
Suite_Com_Code	VBA module which generates Suite LCC Comparison report.
Eq_Com_Code	VBA module which generates Equipment LCC Comparison report.
Eq_LRU_Code	VBA module which generates Equipment LRU Summary report.
LRU_Sens_Code	VBA module which generates LRU Sensitivity Study report.
Seg_Chart	Chart sheet which presents Segment Pareto Analysis.
Seg_Pareto_Code	VBA module which generates Segment Pareto Analysis report.
Suite_Chart	Chart sheet which presents Suite Pareto Analysis.
Suite_Pareto_Code	VBA module which generates Suite Pareto Analysis report.
Eq_Chart	Chart sheet which presents Equipment Pareto Analysis.
Eq_Pareto_Code	VBA module which generates Equipment Pareto Analysis report.
LRU_Chart	Chart sheet which presents LRU Pareto Analysis.
LRU_Pareto_Code	VBA module which generates LRU Pareto Analysis report.

6.2. Data Exchange Workbook

This workbook contains the file of computer code that provides the HELP screens and previously generated trade LCC estimates and analyses. It contains mini tutorials, explanations of input screens, and both databases and generated reports. Along with each database worksheet is a pivot table worksheet that extracts the specific data or studies of interest, and in case of Help screens, explanations, definitions, and examples. Table 6-2 summarizes the sheets in the workbook. Putting these sheets in a separate workbook permits the workbook to be closed when the information is not needed. Assigning a Pivottable to each database permits data to be accessed faster.

Table 6-2. Data Exchange Workbook.

Name of Sheet	Description
Concept Exploration	Database of historical Concept Exploration/Definition phase cost for different avionics suites.
CE_Pivottable	Worksheet that contains pivottable for accessing different types of avionics suites CE/D data.
Dem_Val	Database of historical Concept Demonstration/Validation phase cost for different avionics equipments.
DV_Pivottable	Worksheet that contains pivottable for accessing different types of avionics equipment Dem/Val data.
Equipment	Database of historical LRU types, quantities, and costs contained in different types of avionics equipments.
EQ_Pivottable	Worksheet that contain pivottable for accessing different avionics equipment LRU configurations.
LRU	Database of historical SRU types, quantities, and costs contained in different LRU types.
LRU_Pivottable	Worksheet that contains pivottable for accessing different avionics LRU types.
LRM	Database of LRM types and costs.
LRM_Pivottable	Worksheet that contains pivottable for accessing different avionics LRM types.
CSCI	Database that contains counts of KSLOC, Function Points, Feature Points or CSUs in the software used in or with different avionics equipments.
CSCI_Pivottable	Worksheet that contains pivottable for accessing the different CSCI software complexity in different avionics equipments.
CSC	Database that contains counts of KSLOC, Function Points, Feature Points or CSCs in the software used in or with different avionics LRUs.
CSC_Pivottable	Worksheet that contains pivottable for accessing the different CSCI software complexity in different avionics LRUs.
PSE	Database of test equipment types and costs for the peculiar support equipment used with different avionics equipments and LRUs.
PSE_Pivottable	Worksheet that contains pivottable for accessing the support equipment used with different avionics equipments and LRUs.
Acq_Concepts	Database of instructions for using program to analyze different acquisition concepts.
HW_SW_Imp	Database of instructions for using program to analyze different HW/SW implementations.
Support_Concepts	Database of instructions for using program to analyze different Logistics Support concepts.
Generated	Database of LCC estimates, comparisons, sensitivity studies, and Pareto analyses generated as part of the trade studies conducted for an avionics suite, equipments, and LRUs and CSCIs.
Gen_Pivottable	Worksheet that contains pivottable for accessing the LCC studies developed for different avionics suites, equipments, LRUs, and CSCIs for the Functional, Allocated, and Product design baselines.
Summaries	Module of VBA code that uses Gen_pivottable to formulate a summary list of all trade studies conducted to date on a given avionics suite or equipment.
Dialog	Database of Help screen explanations of Dialog Boxes.
Dia_Pivottable	Worksheet that contains pivottable for accessing the different Help screens the explain Dialog Boxes.

6.3 Output Reports

Three types of reports have been designed to be generated by the Excel application: a life cycle cost estimate, life cycle cost estimate analyses, and life cycle cost comparisons. Two types of LCC analyses have been designed: a Pareto analysis and a sensitivity analysis. The Pareto analysis displays a chart of LCC concentrations. The sensitivity analysis determines which factors have the greatest impact on equipment level life cycle costs.

All reports are keyed to an analyst, a design baseline, a hardware level, the used on aircraft and the assumed deployment and life cycle.

6.3.1 LCC Estimate

Figure 6-2 shows the format designed for reporting life cycle cost estimates. This same format will be used for segment, suite, and equipment LCC estimates. At each level the information for each subordinate level will be in the computer even though it is not printed out until requested. This is to say that in order to estimate segment LCC, the LCC of each of its suites has to be estimated; to estimate suite LCC, the LCC of each equipment in the suite has to be estimated; and to estimate equipment LCC, either the LCC of each LRU and/or LRM and CSCI has to be estimated or default LRU, LRM, and CSCI accepted.

All phases of the life cycle are estimated for all hardware and software levels, however in the early phases (CE and Dem/Val) generalizations about LRU, LRM, and CSCI designs may be necessary and, based on the decision needed, desirable.

Study Title ______________________________ Date __________
Analyst Name ______________________________ Org ______________
A/C Design Series & Mission ______________ Design Baseline _(Functional, Allocated, Product)
Level: _(Segment or suite or Equipment)_____ No Built _______ LRIP _______ Rate Prod _______
Deployment: Number of Bases CONUS _____ Overseas _____
Number of Depots CONUS _____ Overseas ______
Life Cycle (Years): CE _____ Dem/Val _____ EMD _____ LRIP _____ Rate Prod _____ O&S ____
Number of Contracts: CE ____ Dem/Val _____ EMD _____ LRIP _____ Rate Prod _____ O&S ____
Life Cycle Start Date ________________ P^3I Start Date ____________________
(Then or Constant) Year Dollars (Millions)

	R&D COST			INVESTMENT		O&S	
LCC ELEMENTS	CE	DEM/VAL	EMD	LRIP	RATE	O&S	TOTAL
Prime Mission Equipment	X	X	X	X	X		X
Sys/Appl Software	X	X	X				X
Test & Evaluation		X	X	X	X		X
System Engr/Prog Mgmt	X	X	X	X	X		X
Peculiar Support Equip.		X	X	X	X	X	X
Training			X	X	X	X	X
Data	X	X	X	X	X	X	X
Initial Spares				X	X		X
Base Level Maintenance						X	X
Base Level Consumption						X	X
Personnel Support						X	X
Depot Maintenance						X	X
Depot Consumption						X	X
Contractor Support						X	X
Inventory Maintenance						X	X
Software Maintenance						X	X
TOTAL LCC	X	X	X	X	X	X	X

Figure 6-2. Segment, Suite, or Equipment Level LCC Estimate Reports.

6.3.2 Life Cycle Cost Comparisons

Figure 6-3 shows the format for the Avionics Segment, Suite, or Equipment Level LCC Comparisons that can be developed with the designed program. Cost comparison reports compare the cost of LCC elements and total life cycle cost for two different sets of Avionic Segments, or Suites, or Equipments, and the differences (LCC Deltas) between them. They will not, however, show the differences in life cycle phase costs, nor the differences in acquisition policies used, if any. For those differences, the user will have to compare phased LCC estimates.

Study Title ______________________			Date ________
Analyst Name ______________________			Org ________
A/C Design Series & Mission ________		Design Baseline (Functional, Allocated, Product)	
Level: (Segment, Suite, Equipment) ________	No Built ______	LRIP ________	Rate Prod ______
Deployment: Number of Bases CONUS _____	Overseas _____		
Number of Depots CONUS _____	Overseas _____		
Life Cycle (Years): CE _____ Dem/Val _____	EMD _____	LRIP _____ Rate Prod _____	O&S ____
Life Cycle Start Date ______________			
	(Then or Constant) Year Dollars (Millions)		
	Design Case (Identifier)	Design Case (Identifier)	Life Cycle Cost
LCC ELEMENTS	Total LCC	Total LCC	Deltas
Prime Mission Equipment			
Sys/Appl Software			
Test & Evaluation			
System Engr/Prog Mgmt			
Peculiar Support Equip.			
Training			
Data			
Initial Spares			
Base Level Maintenance			
Base Level Consumption			
Personnel Support			
Depot Maintenance			
Depot Consumption			
Contractor Support			
Inventory Maintenance			
Software Maintenance			
TOTAL			

Figure 6-3. Segment, Suite, or Equipment Level LCC Comparisons Report.

6.3.3 Equipment LRU or LRM Summary Reports

Figure 6-4 shows the format designed for the Equipment LRU or LRM summaries that can be developed with the designed program. These reports tabulate the LRUs or LRMs within an equipment and their principal LCC related characteristics as well as their contribution to the equipment's overall life cycle cost. The Equipment LCC contribution includes an allocation of LRU or LRM related technical order, inventory, peculiar support equipment development costs, and maintenance cost.

Study Title ______________________________ Date ________

Analyst Name ______________________________ Org ______________

A/C Design Series & Mission ______________ Design Baseline _(Functional, Allocated, Product)

Equipment ____________________ Build ______ LRIP ______ Rate Prod ______

Deployment: Number of Bases CONUS _____ Overseas _____

Number of Depots CONUS _____ Overseas _____

Life Cycle (Years): CE _____ Dem/Val _____ EMD _____ LRIP _____ Rate Prod _____ O&S ____

Life Cycle Start Date ______________________

LRU/LRM LCC SUMMARY

(Then or Constant) Year Dollars (Thousands)

LRU/LRM Name	QTY	Unit Cost	MTBF	MTTR	Int Spares	Base Repairs	Depot Repairs	Equip LCC Contribution
TOTAL								

Figure 6-4. Equipment LRU or LRM Summary Report.

6.3.4 LRU or LRM Sensitivity Study Reports

Figure 6-5 shows the format designed for an analysis of an equipment's LCC sensitivity to its LRU or LRM's characteristics. These reports estimate the life cycle cost of a given LRU or LRM in an equipment in a given deployment for a range of MTBFs, MTTRs, and Unit costs. Like the Equipment LRU summary, the sensitivity study LCC estimate includes an allocation of development costs and peculiar support equipment cost. Also, the LCC estimates are developed with only one characteristic changed for a given estimate. For instance, if the MTBF is changed then the MTTR and unit cost are held constant, similar consideration holds for MTTR and unit cost changes.

Study Title ____________________ Date ________

Analyst Name ____________________ Org ________

A/C Design Series & Mission ____________ Design Baseline ____ (Functional, Allocated, Product) ____

Equipment ____________ Build ______ LRIP ______ Rate Prod ______

Deployment: Number of Bases ________ CONUS ____ Overseas ____

Number of Depots ________ CONUS ____ Overseas ____

Life Cycle (Years): CE ____ Dem/Val ____ EMD ____ LRIP ____ Rate Prod ____ O&S ____

Life Cycle Start Date ____________

LRU/LRM SENSITIVITY SUMMARY

(Then or Constant) Year Dollars (Thousands)

LRU/LRM NAME	MTBF RANGE LCC				MTTR RANGE LCC				UNIT COST RANGE LCC			
	Upper		Lower		Upper		Lower		High		Low	
	MTBF	LCC	MTBF	LCC	MTTR	LCC	MTTR	LCC	COST	LCC	COST	LCC

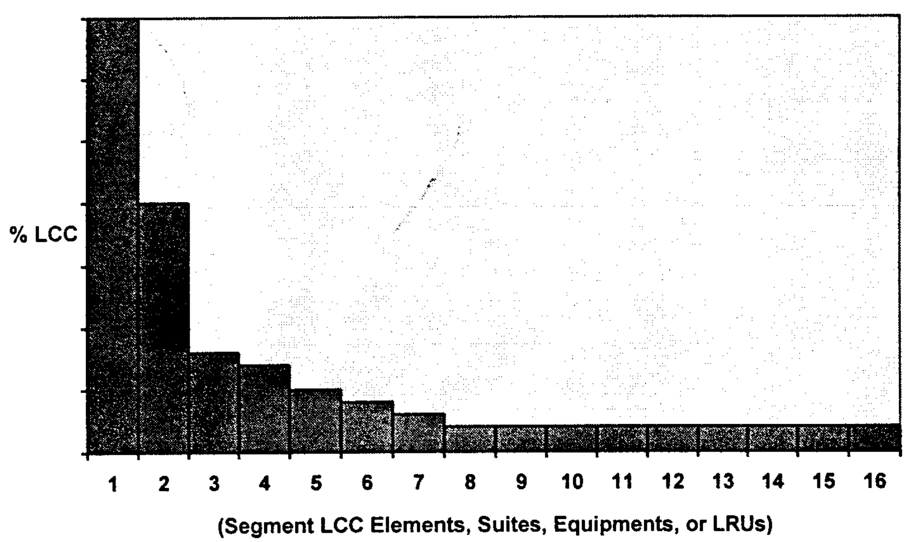
Figure 6-5. LRU/LRM Sensitivity Study Report.

6.3.5 Suite and Equipment Level LCC Pareto Analysis

Figure 6-6 shows the format designed for a Pareto analysis of the different LCC elements to a given suite or equipment's LCC; or a Pareto analysis of the contribution of the different equipments to a suite's LCC; or a Pareto analysis of the contribution of the different LRUs to an equipment's LCC. A Pareto analysis presents a graphical representation of the cost concentrations within a LCC estimate. The abscissas represents the percent of LCC contributed by the LCC elements, suites, equipments or LRUs/LRMs identified on the ordinate.

Study Title ______________________________ Date __________
Analyst Name ______________________________ Org __________
A/C Design Series & Mission ______________ Design Baseline (Functional, Allocated, Product)
Level: (Segment, Suite, Equipment)______ Build ______ LRIP ______ Rate Prod ______
Deployment: Number of Bases __________ CONUS _____ Overseas _____
Number of Depots __________ CONUS _____ Overseas _____
Life Cycle (Years): CE _____ Dem/Val _____ EMD _____ LRIP _____ Rate Prod _____ O&S _____

PARETO ANALYSIS



1.	9.
2.	10.
3.	11.
4.	12.
5. LCC Suites Equipments LRUs	13. LCC Suites Equipments LRUs
6. Elements	14. Elements
7.	15.
8.	16.

Figure 6-6. Segment, Suite, and Equipment Level Pareto Analysis.

6.4 Inputs

Figure 6-7 summarizes an analysis made to determine the information needed by Excel to develop the designed output reports and its source (input or stored). In figure 6-7, a downward arrow symbol ↓ indicates that the information is furnished to the user for his selection from a DropDown box; a box symbol indicates the user will input into an edit box; an edit box followed by the word, help, or default and a check box symbol X means the user can input, ask for help, or use a stored default. A check box symbol alone means a designation for an action. The arrows from one information grouping to another trace the flow of an input to its appearance on the screen at the next level. For instance, the name entered for an equipment as part of the suite dialog becomes an automatic entry in an equipment dialog box. A ○ means the user can select from the listed alternatives on a dialog box.

The following information groupings were defined for program inputs: Development, Segment, Suite, Equipment, LRU/LRM, CSCI, SRU, Deployment, Support, Global, and Sensitivity.

<u>Development Inputs</u>: Aircraft design series, mission, CE Phase years, CE start year, number of CE phase contracts, Dem/Val phase years, Dem/Val start year, number of Dem/Val phase contracts, EMD phase years, EMD start year, number of EMD contracts.

<u>Segment Level inputs</u>: Number of suites, architecture, suite names.,

<u>Suite Level inputs</u>: Number of equipments, equipment names, equipment unit cost, equipment installation cost, designation as to whether or not an LRU or LRM level analysis is required.

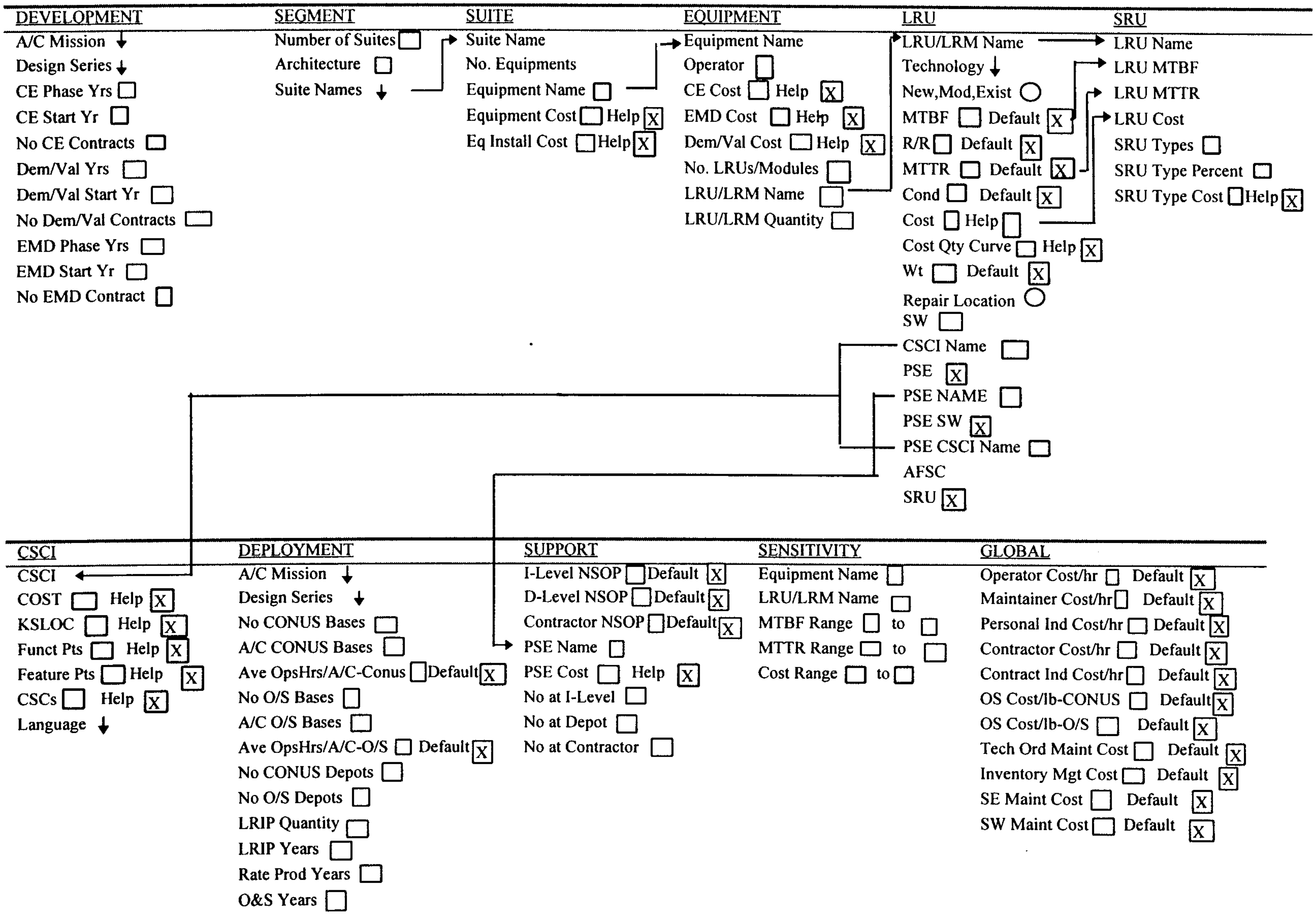


Figure 6-7. Data for LCC Estimation and Analysis.

Stored Databases	Help Databases	Default Databases
A/C Missions	CE cost	Integration Cost
Design Series	Dem/Val Cost	Operator Cost/hr
Suite Name/Function	EMD Cost	Maintainer Cost/hr
CSCI Languages	Equipment Cost	Contractor Cost/hr
AFSC	Install Cost	Personnel Indirect Cost/hr
Development Factors	LRU Technology	Contractor Indirect Cost/hr
Escalation Factors	LRU Cost	OS Cost/lb CONUS
Study Titles	LRM Technology	OS Cost/lb O/S
	LRM Cost	Tech Ord Maint Cost
	SRU Types	Inventory Mgt Cost
	SRU Cost	Support Eq Maint Cost
	CSCI Types	SW Maint Cost
	CSCI Cost	LRU MTBF
	KSLOC	LRM MTBF
	Function Points	LRU R/R Time
	Feature Points	LRM R/R Time
	CSCs	LRU MTTR
	PSE Cost/Type	LRM MTTR
	Acq Concepts	LRU Cond
	Hw/Sw Trades	LRM Cond
	Logistic Concept	LRU Wt
	Dialog Box Inputs	LRM Wt
		SRUCost/Type
		I-Level NSOP
		D-Level NSOP
		C-Level NSOP

Figure 6-7. Data for LCC Estimation and Analysis (cont'd).

Equipment Level Inputs: CE phase cost, Dem/Val phase cost, EMD phase cost, designation as to whether or not an operator is required, the number of LRU types, and the names of the LRU types. Note: CE, Dem/Val, and EMD phase cost are optional direct input overrides, otherwise these costs are estimated with CERs.

LRU Level Inputs: Designation as to whether LRU type is new, existing, or modification, LRU technology, unit cost, cost/quantity curve, use in other equipments, use in other aircraft, MTBF, remove/replace time, repair level, MTTR, condemnation rate, weight, designation of embedded software, CSCI name, designation of peculiar support equipment (PSE) requirement, PSE name, designation of PSE software, name of PSE CSCI, designation of special maintenance technician, name of military specialty, designation of SRU level assessment required.

CSCI Level Inputs; Designation as to whether CSCI is new, existing or modification, CSCI type, software language, CSCI Cost, and thousands of source lines of code, function points, feature points, or computer software components.

SRU Level Inputs: SRU types within an LRU, (Analog, Digital, Stripline, Microwave, IR, Mech/ElectroMech, other), percent of SRUs within LRU of a given type, cost of SRU type, help for determining SRU cost. Note: These are initial categories of SRU types. They may be changed with further investigation.

Deployment Inputs: Aircraft mission and mission design series, number of CONUS bases, number of aircraft per CONUS base, monthly operating hours per CONUS base aircraft, number of overseas bases, number of aircraft per overseas base, monthly operating hours per overseas based aircraft, number of CONUS depots, number of overseas depots, number of LRIP contractors, LRIP quantity, LRIP years, number of rate production contractors, rate production quantity, rate production years, number of operating and support years contractor support years, and organic support years..

Support Inputs: Peculiar support equipment cost, designation of PSE locations (Intermediate, Depot, Contractor), number of PSE per type per location, no stock out probability for LRUs at intermediate, no stock out probability for LRUs at depot, and no stock out probability for LRU at contractor.

Global Inputs: Operator cost per hour, maintainer cost per hour, indirect personnel cost per hour, contractor maintenance cost per hour, order and ship cost per pound to and from CONUS depot, order and ship cost per pound to and from overseas depot, order and ship cost per pound to and from contractor, equipment technical order maintenance cost, equipment inventory management maintenance cost, support equipment maintenance cost, software maintenance cost.

Sensitivity Inputs: Equipment, LRU or LRM high and low MTBF range, LRU or LRM high and low MTTR range, LRU or LRM high and low cost range.

Much of the information to be used for LCC estimating and analysis will be contained in databases stored in the program prior to user inputting. These databases are identified as Stored databases, Default databases, and Help databases.

Stored databases: will contain the names of avionics functions, subfunctions, aircraft missions and mission design series, LRU technology classifications, CSCI type classifications, software languages, SRU types, PSE types, AF specially codes, escalation factors, development cost allocation factors, and study titles.

Default databases: will contain order and ship cost per pound to and from depots, order and ship cost per pound to and from contractor, technical order maintenance cost, support equipment maintenance cost, software maintenance cost, integration cost, operator cost/hour, maintainer cost/hour, contractor cost/hour, personnel indirect cost/hour, contractor indirect cost/hour, LRU MTBFs, LRM MTBFs, LRU R/R times, LRM R/R times, LRU MTTRs, LRM MTTRs, LRU condemnation rates, LRM condemnation rates, LRU weights, LRM weights, and SRU cost/type.

Help databases: will contain historical CE, Dem/Val, and EMD phase costs, typical equipment costs per type and technology; typical LRU and LRM costs per type and technology; typical SRU costs per type and technology; typical CSCI type costs, typical CSCI type KSLOC, typical CSCI type function points, typical CSCI type feature points, typical CSCI CSCs, typical PSE cost/type, example acquisition concept studies, example hardware and software implementation studies, example logistic concept studies, and explanations of dialog box inputs.

6.5 Flow

Figure 6-8 shows the computer screen flow designed for the Excel application. There will be an opening screen (figure 6-9) that controls the program start, or exit. This will lead to an Option screen (figure 6-10) that will let the user either develop a design support study, or receive instruction on how to apply the program to different types of trades, or view past studies. If the develop option is selected, a study identifier screen (figure 6-11) will ask for study title, date, analyst name and organization, and the identification as to which design baseline the study applies (Functional, Allocated, or Product) and the hardware level being studied. This will be followed by a level of analysis screen (figure 6-12) that selects the analysis level (segment, suite, equipment, LRU/LRM or CSCI), and a development dialog (figure 6-13) that inputs the life cycle phase information.

A user electing to generate a segment level study steps from segment (figure 6-14) to suite (figure 6-16) to equipment (figure 6-18) to LRU/LRM (figure 6-20) and/or SRU, if applicable, (figure 6-21) and/or CSCI (figure 6-22) then deployment (figure 6-24), support (figure 6-25) and global (figure 6-26), comparison decision (figure 6-27) and then returns to level selection (figure 6-12) or view and print (figure 6-29). After Segment, Suite, and Equipment inputs, another set of inputs are asked for until the levels are filled (figures 6-15, 6-17, 6-19). The user selecting to conduct a suite level study, steps to development, suite, equipment, LRU/LRM and/or SRU, if applicable, and/or CSCI, then deployment, support, global, comparison decision, and returns to level or View/Print selection. The user selecting an equipment level study, steps to development, equipment, LRU/LRM and/or SRU, if applicable, and/or CSCI, then deployment, support, global, comparison decision and returns to level or View/Print selection. The user selecting an LRU or LRM or CSCI level study, steps directly to development, then the LRU/LRM or CSCI input then SRU, if applicable, then deployment, support, global, comparison decision and returns to level or View/Print selection. The user wanting to do a sensitivity

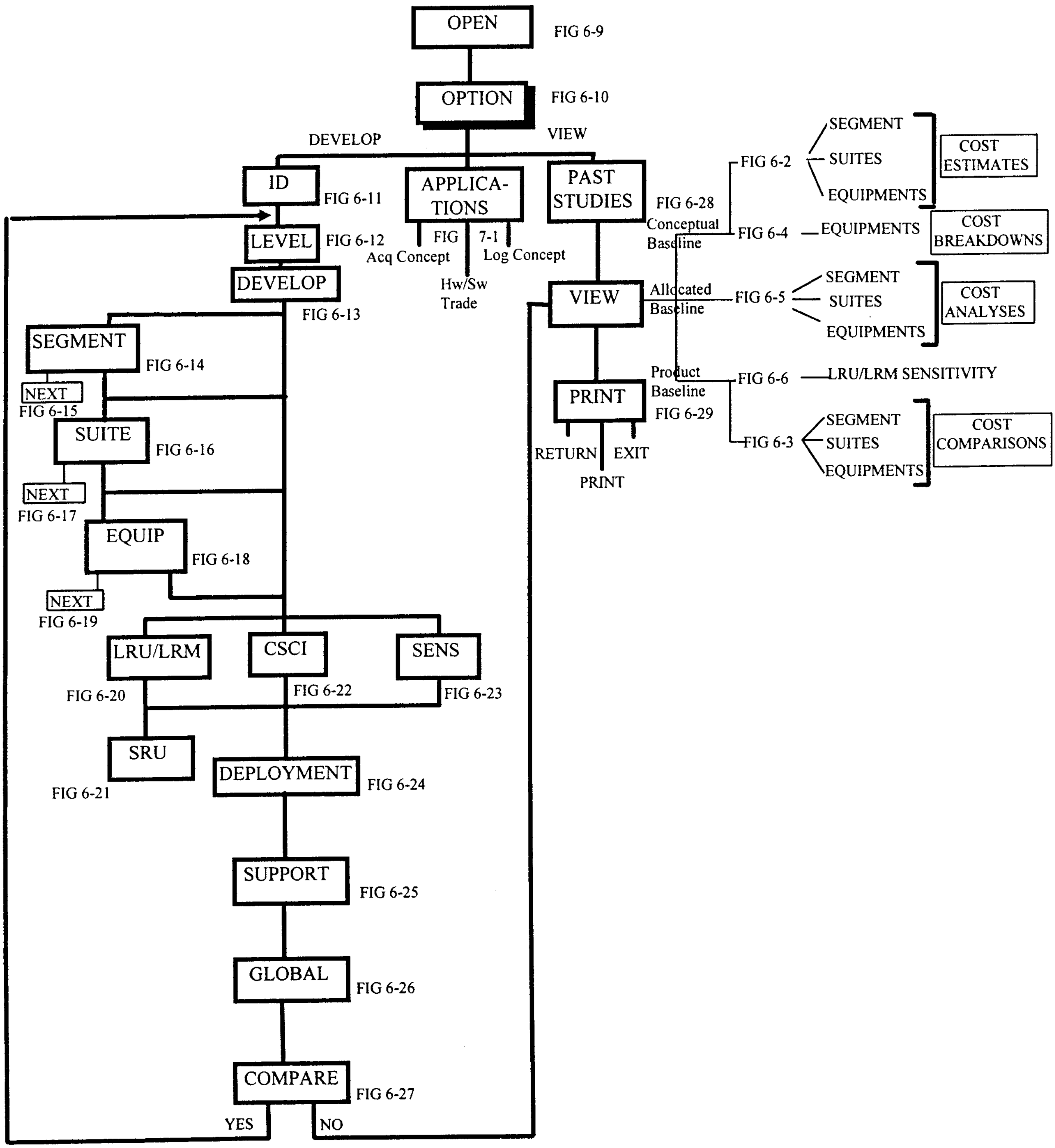


Figure 6-8. Computer Screens Flow.

study, steps to development, equipment, LRU/LRM, then sensitivity, deployment, support, global, and returns to View/Print selection.

The user wanting to review the LCC analyses that have been conducted on a design baseline and then edit view or print a given study report(s), first views the history (figure 6-28), then selects the reports of interest, then either prints the reports (figure 6-24) or returns to the start.

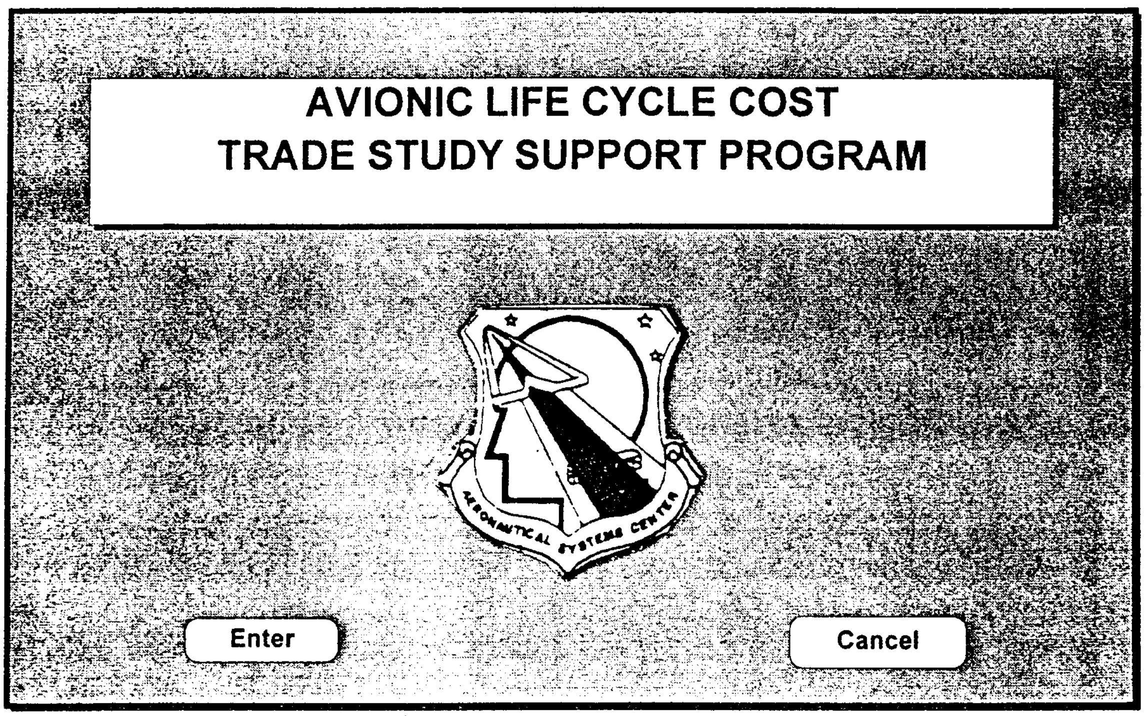


Figure 6-9. Open_Control Screen

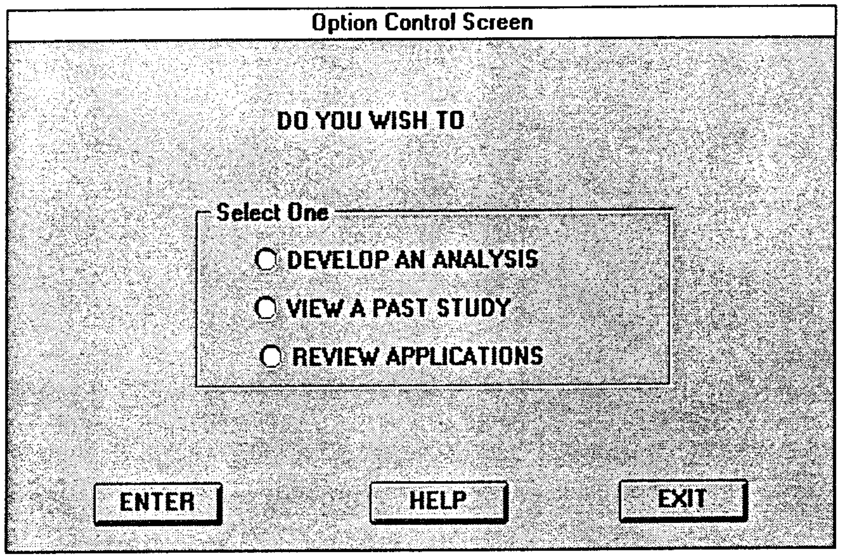


Figure 6-10. Option_Control Screen.

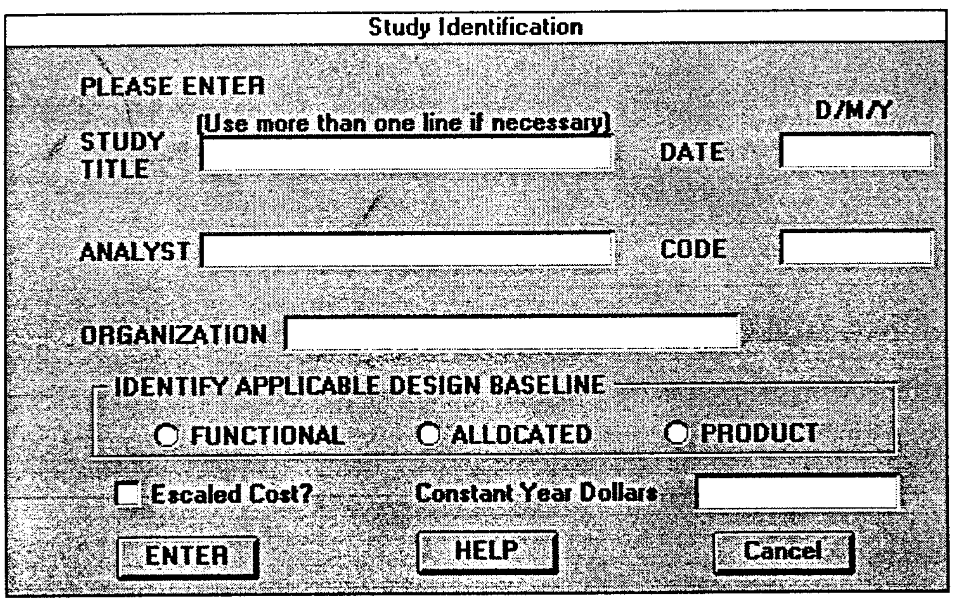


Figure 6-11. ID_Dialog Box

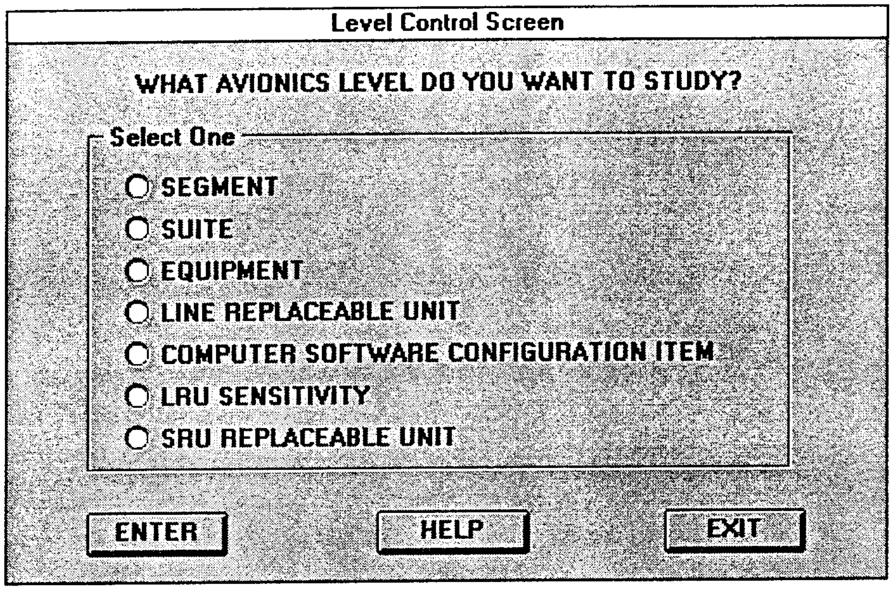


Figure 6-12. Level_Control Dialog Box.

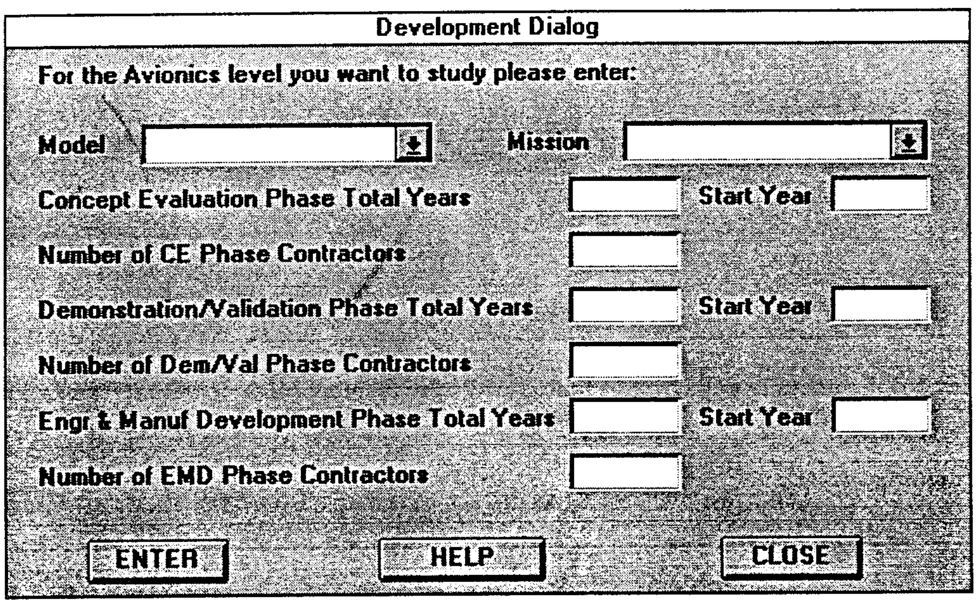


Figure 6-13. Development Dialog Box.

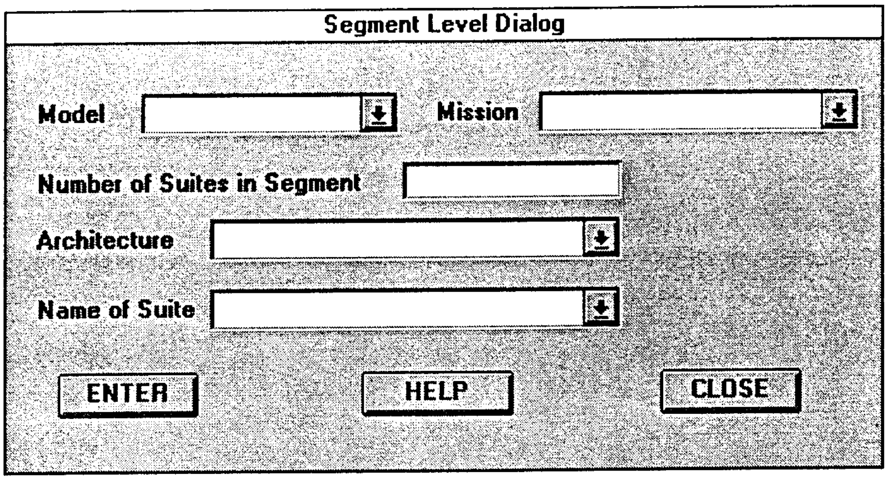


Figure 6-14. Segment Dialog Box.

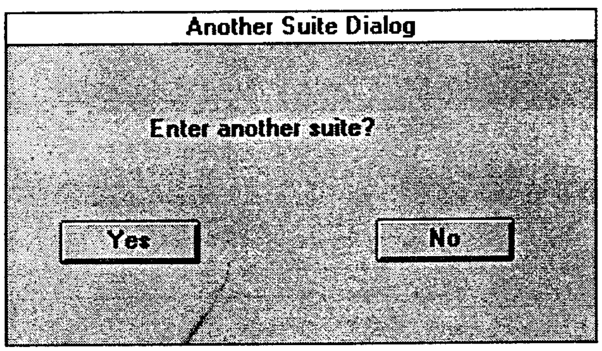


Figure 6-15. Another_Suite Dialog Box.

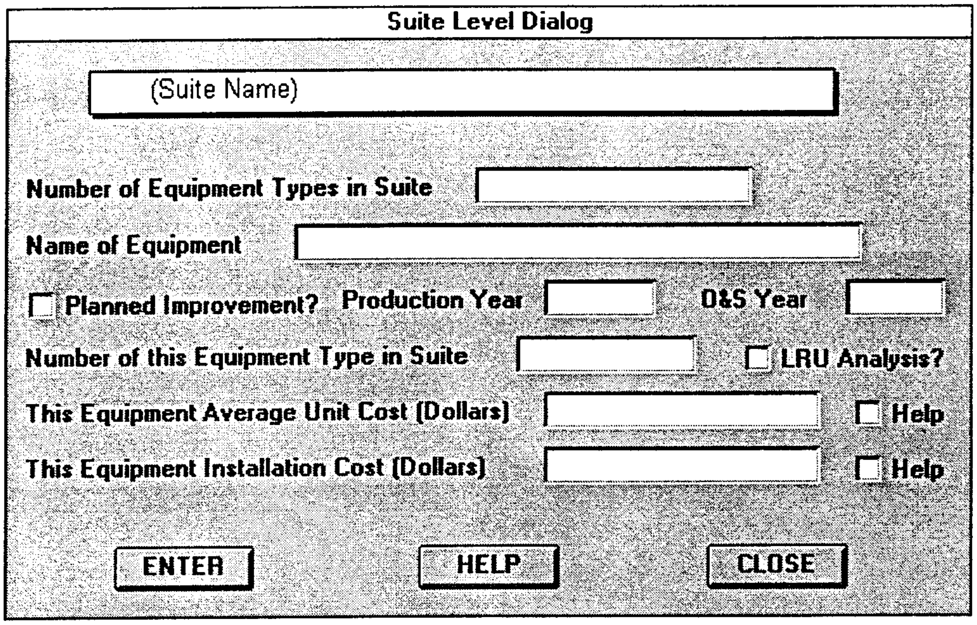
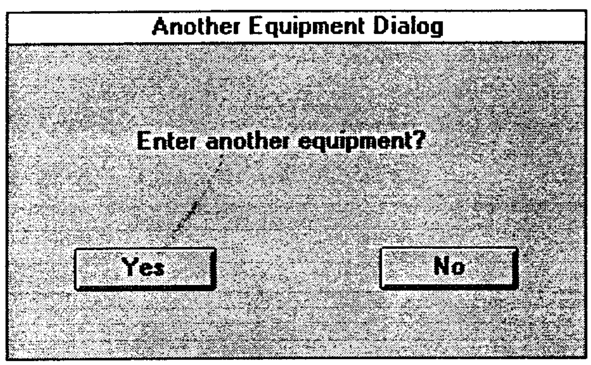


Figure 6-16. Suite Dialog Box.



Fiure 6-17. Another_Equipment Dialog Box.

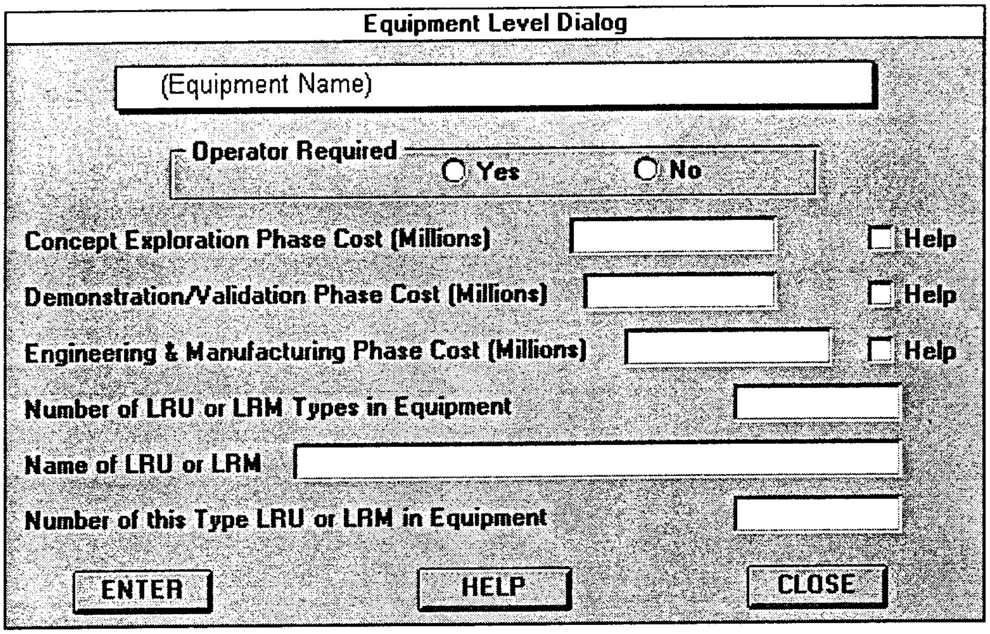


Figure 6-18. Equipment Dialog Box.

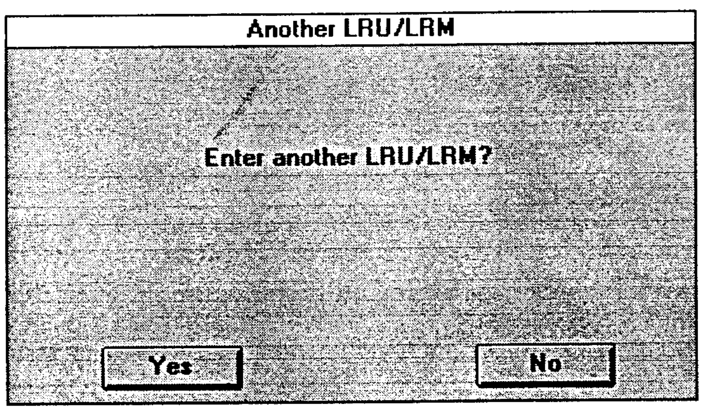


Figure 6-19. Another_LRU Dialog Box.

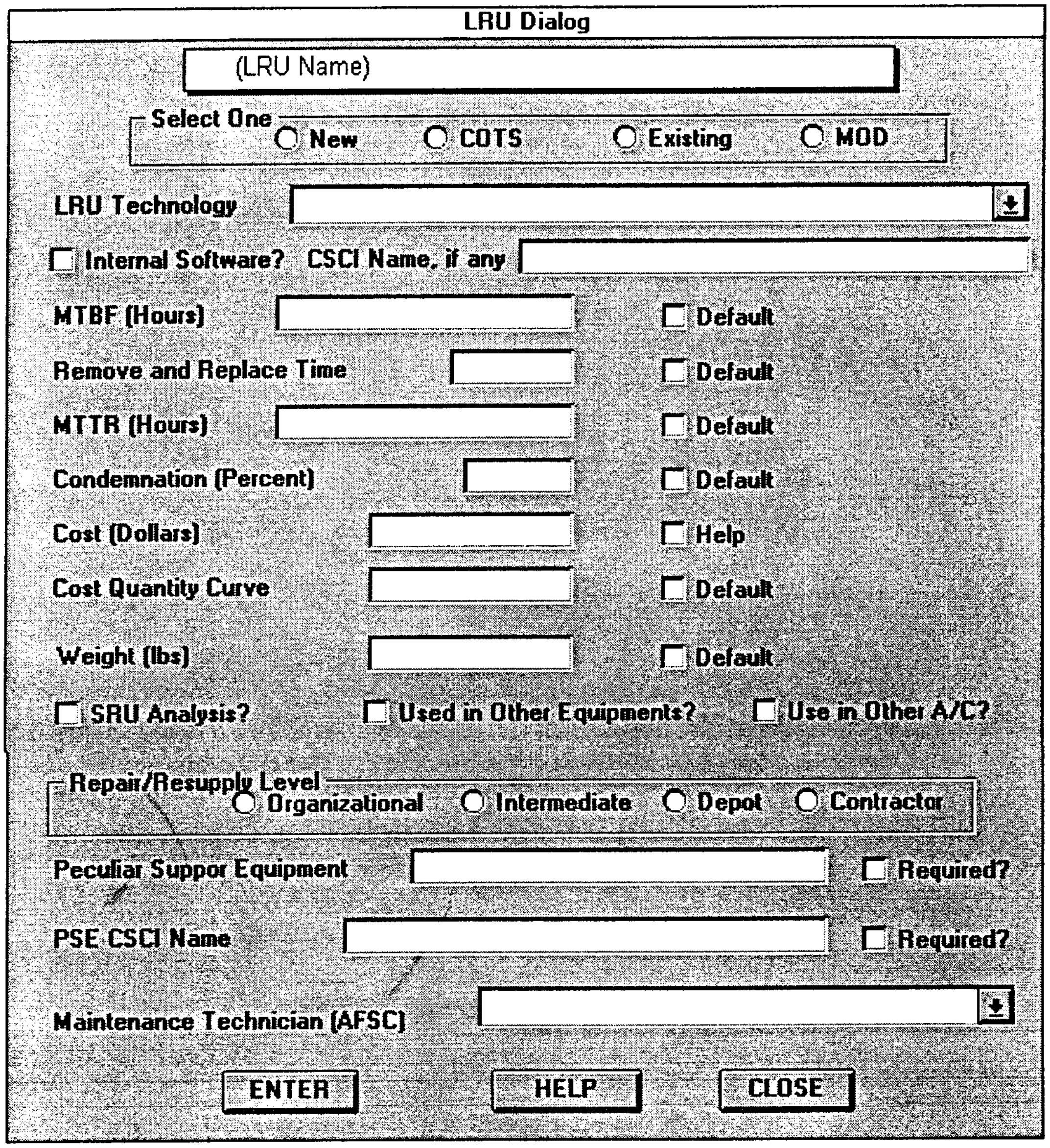


Figure 6-20. LRU Dialog Box.

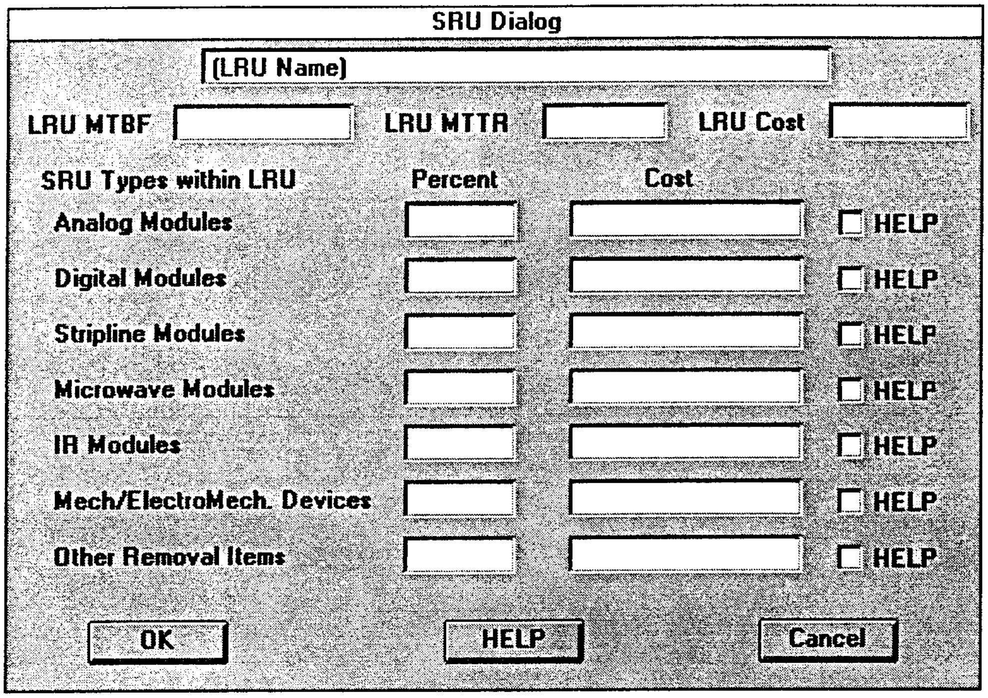


Figure 6-21. SRU Dialog Box.

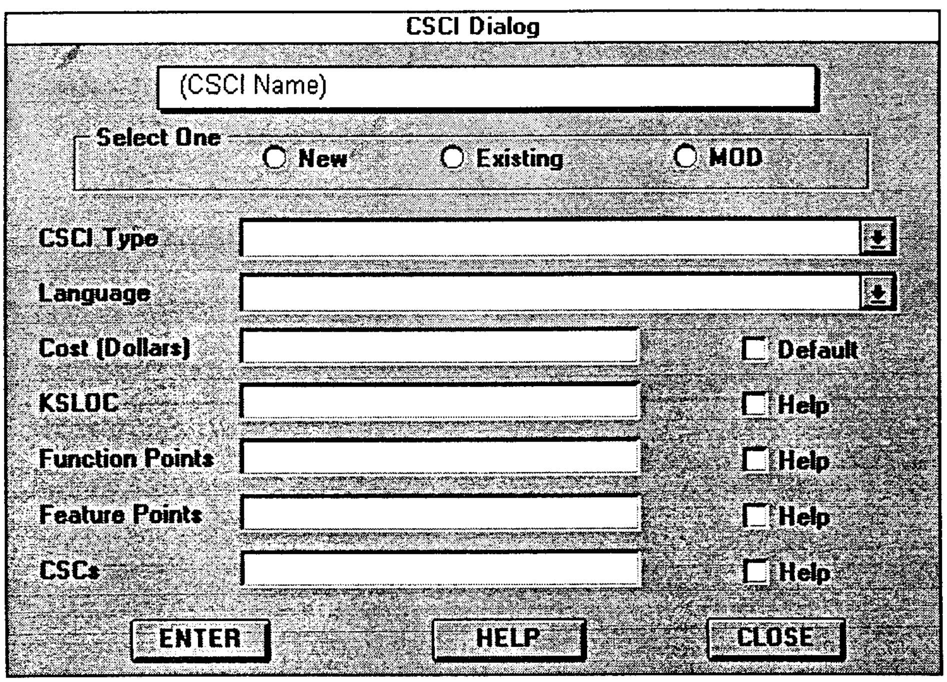


Figure 6-22. CSCI Dialog Box.

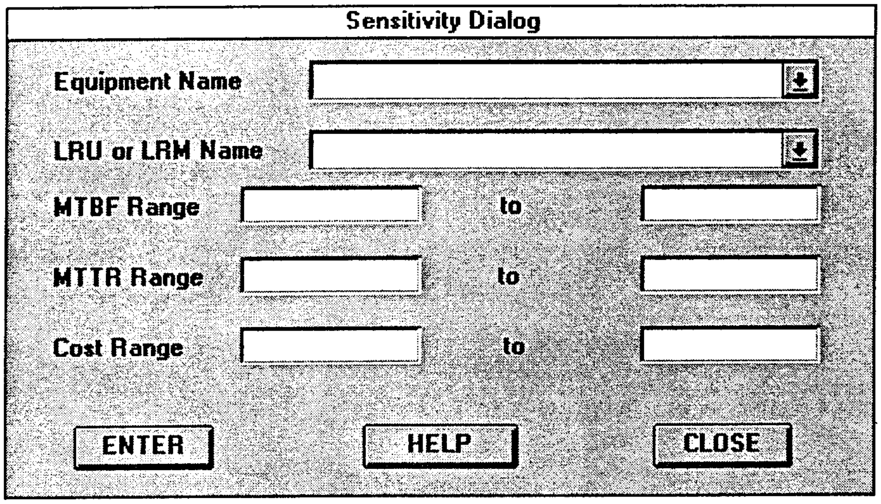


Figure 6-23. Sensitivity Dialog Box.

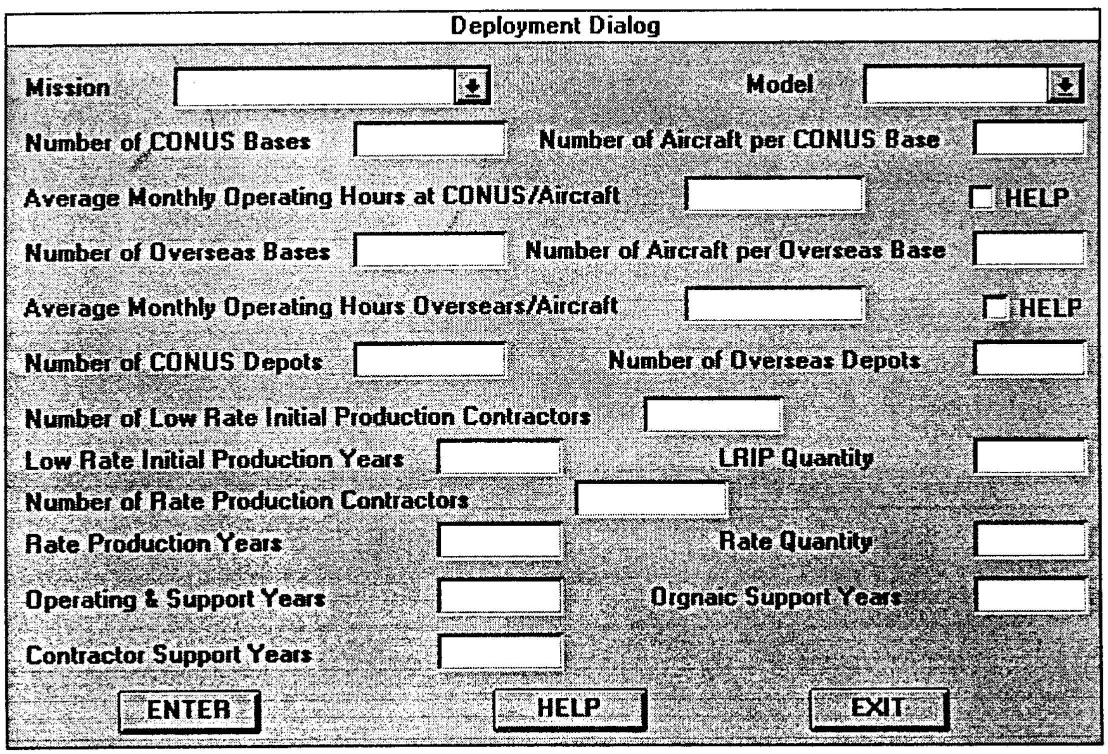


Figure 6-24. Deployment Dialog Box.

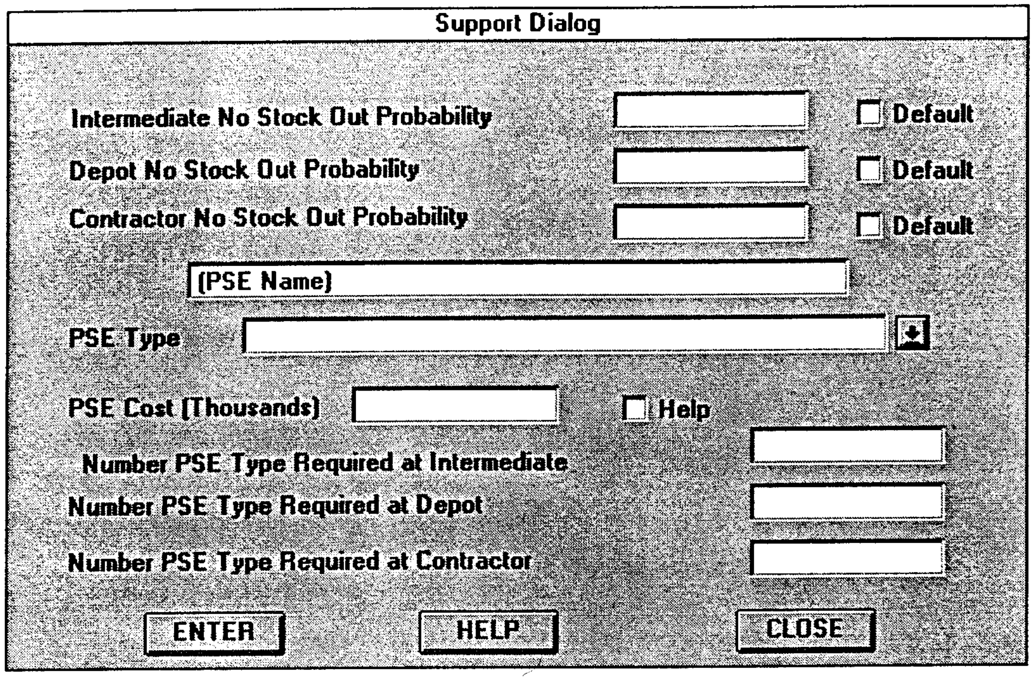


Figure 6-25. Support Dialog Box.

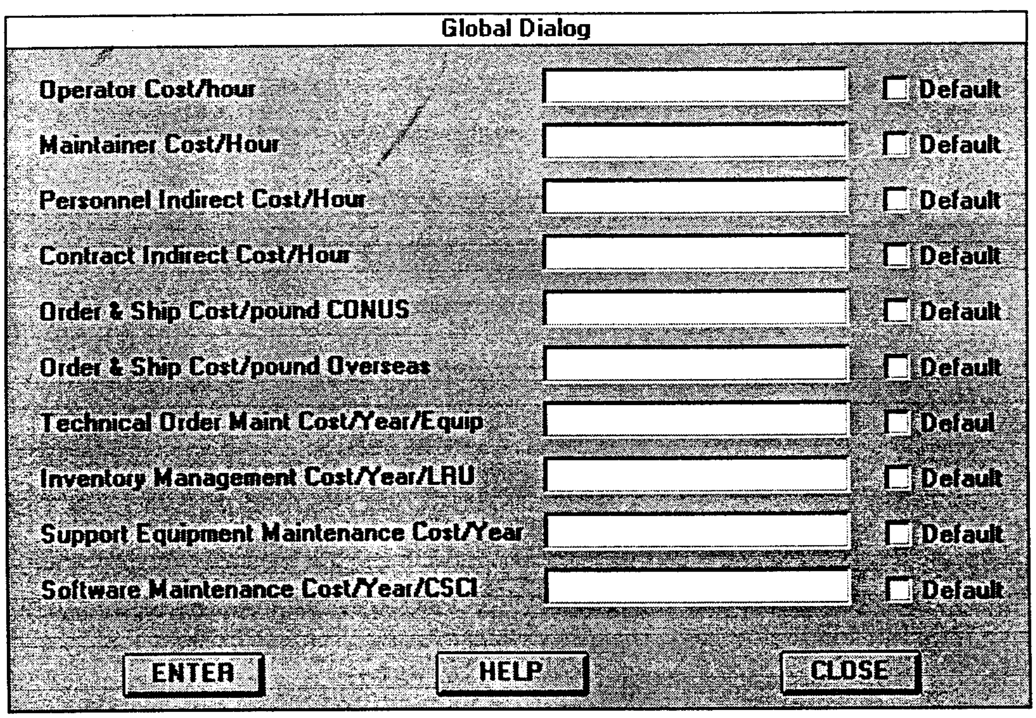


Figure 6-26. Global Dialog Box.

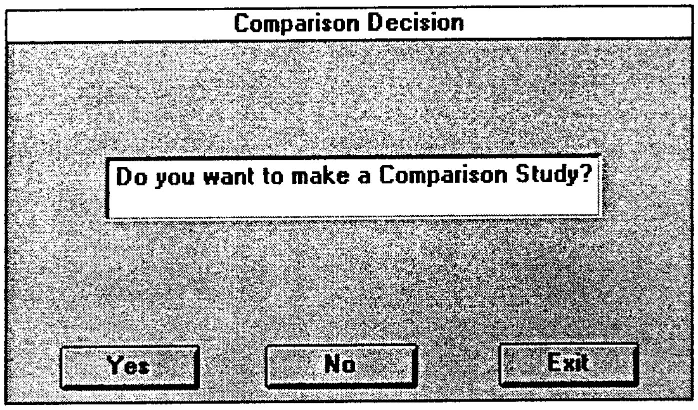


Figure 6-27. Comparison_Decision Control Screen.

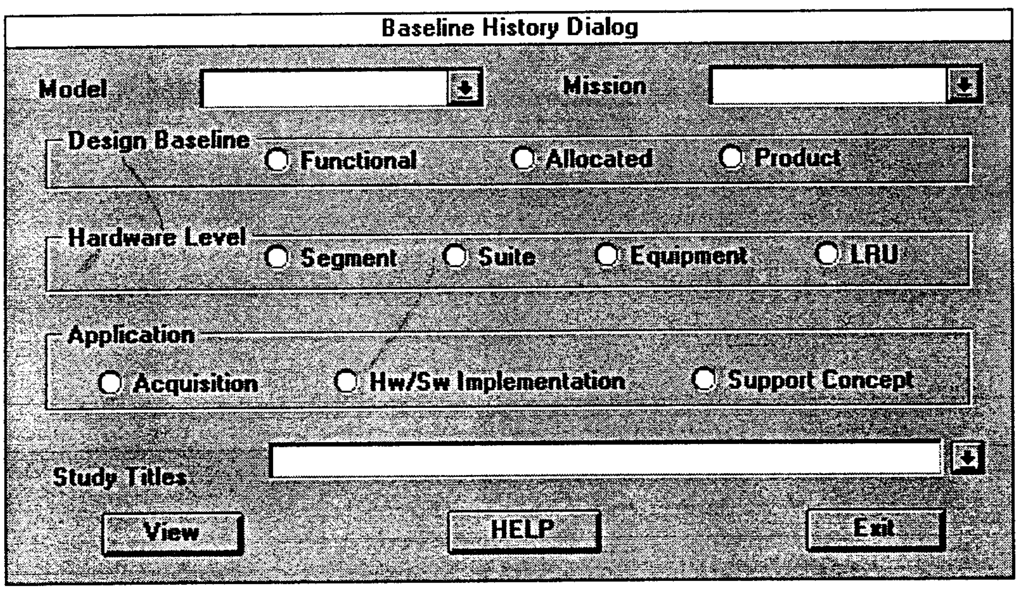


Figure 6-28. Baseline History Dialog Box.

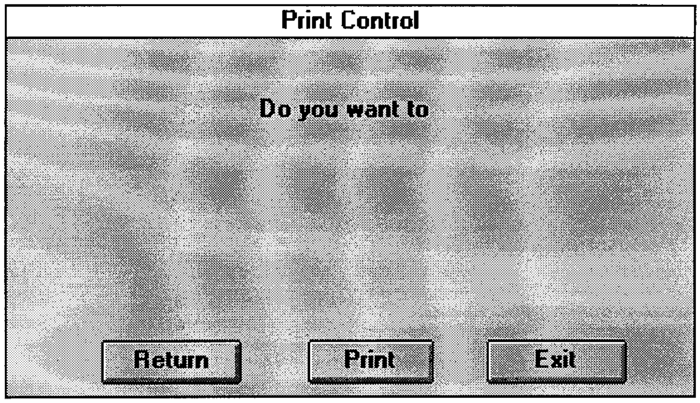


Figure 6-29. Print_Control Screen.

7. Program Applications

The conceptually designed Excel application has been structured to serve throughout avionics development. It was designed to aid in acquisition concept tradeoffs, hardware and software implementation tradeoffs, and operation and support concept tradeoffs. The user may elect to receive instruction on how to use the application for the different types of trades. An application instruction screen (figure 7-1) has been designed to provide selection of Help screen mini-tutorials.

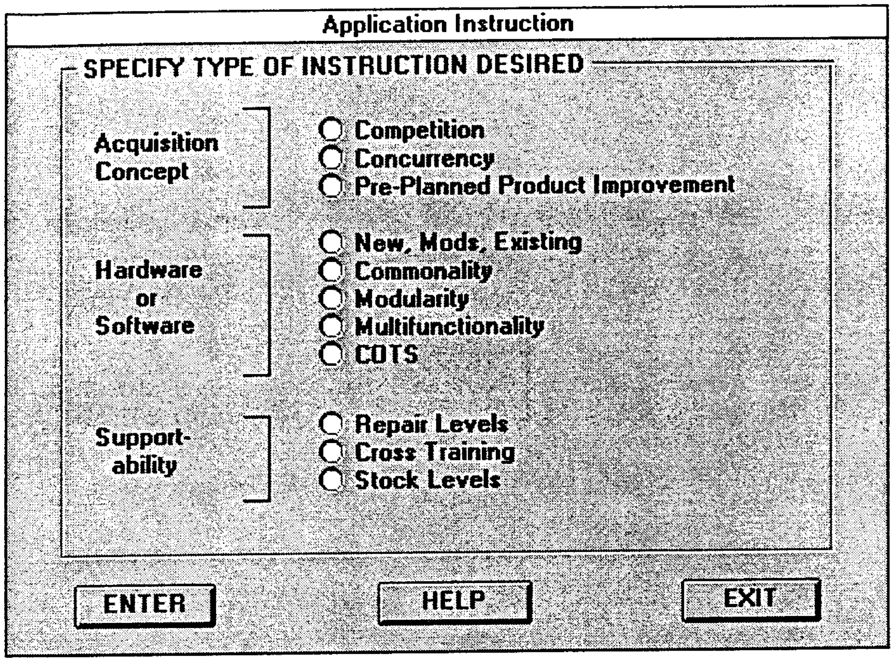


Figure 7-1. Application Instruction Screen.

7.1 Acquisition Concept Tradeoffs

Acquisition concept tradeoffs are primarily concerned with whether or not there is competitive prototyping and production, pre-planned product improvements (P^3I), concurrency of development testing and production, development stretch outs, reductions, or production stretch outs.

7.1.1 Competition

Competition will be analyzed with the application by direct inputs to the development and equipment dialogs. The number of contractors plus the total estimated cost for CE, Dem/Val, EMD, LRIP and Rate Production are inputs. These inputs will be correlated to historical costs of similar equipments.

Low rate initial production and rate production competition will be analyzed by inputting the number of contractors and the quantity of units built in each phase. Learning curve theory will be used to estimate production costs. If competing contractors are not introduced in LRIP, then a shift and rotation of the cost/quantity curve is applied during rate production based on historical cost reductions related to different type equipments.

7.1.2 Product Improvements

Pre-planned product improvement (P^3I) is an acquisition strategy beginning at the system's concept phase to facilitate evolutionary cost-effective upgradings of a system throughout its life cycle. The difference between product improvement (PI), planned product improvement (P^2I), and pre-planned product improvement (P^3I) is in the phase during which improvements are planned [25]. Product improvement occurs after the fact; i.e., the system is in the field, and an improvement is designed and retrofitted to the existing system. In planned product improvements, the system is in full development; or improvement is designed for fit at a later time. In pre-planned product improvement, the system is in the concept phase, no firm interfaces or specifications are present, but plans for incorporating improvements at a later time are developed before the design is set. Awareness of new, developing technology allows the planning of future improvements before the system and interfaces are set in concrete and allows the new technology to be incorporated at a time when the technology is less risky and expensive to apply. In the meantime, a system is fielded in a shorter time because design stability is achieved at an earlier date; cost is reduced because development is less risky; and support and maintenance are better defined.

Product improvements will be input with the Suite level dialog along with the production or O&S year they will be inserted. The average unit cost calculations along with amortized development cost will be used to determine their impact on life cycle cost.

7.1.3 Concurrency

Often there are overlapping activities associated with the phases of an acquisition program. Such overlapping of phases is known as concurrency. The most common form of such concurrency is the production of a system while developmental activities are still ongoing. Figure 7-2 shows an operational schematic of concurrency. The risk of concurrency is offset by using a LRIP phase. Concurrency will be simulated by inputting shorter development times and calculating associated, higher cost development costs.

7.1.4 Stretch-outs

Stretch-outs of the different acquisition phases often occur due to funding delays or reductions. These reductions generally impact the engineering and manufacturing development phase cost. Stretching out of the development phase will be simulated with the program by increasing the length of the phase and its cost proportionally. Stretch-outs can also be reflected in the number of contracts involved in a given phase of development. Stretch-outs of product are analyzed in the application by cost-quantity curves correlated to optimum production rates.

7.1.5 Reductions

Like stretch-outs, funding reductions will be simulated by changing the number of contractors involved in a phase or in quantities produced. These reductions will be compensated for in the application by using cost-quantity curve theory, and by higher production support (i.e. system engineering/program management and data) cost calculations.

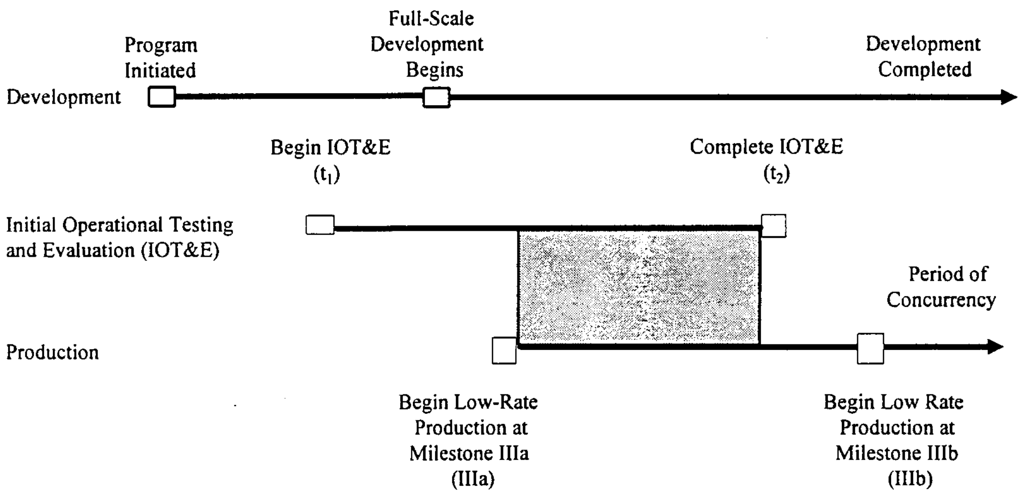


Figure 7-2. Operational Schematic of Concurrency.

7.2 Hardware and/or Software Implementations

Hardware and software implementation tradeoffs will be primarily concerned with whether to implement an equipments design with new, modified, or existing military hardware or software; or to use commercial off-the-shelf (COTS) hardware or software; and to evaluate the impact of commonality, modularity, and multifunctionality on life cycle cost.

Hardware and software implementation tradeoffs will be conducted at the equipment and LRU or LRM levels.

7.2.1 New/Modified/Existing

The use of modified or existing equipments in an avionics suite will be identified at the LRU or LRM level, but it will reflect directly on the cost of engineering and manufacturing development which is input or calculated at the equipment level. Also, in calculating unit production cost application will assume that modifications are further

down the cost-quantity curve than a new unit and that existing LRUs or LRMs are even further down the curve.

7.2.2 Commonality

Commonality will be identified at the equipment, LRU, or LRM level. For instance, at the equipment level it could be like the Pave Pillar common integrated processor, at the LRU level it could be common power supplies or antennas, and at the LRM level it could be common RF modules. Its effect will be to reduce unit cost, reduce initial spares cost, and possibility reduce manning, training, and peculiar support equipments cost. Multiple use of an LRU or LRM is identified during the LRU or LRM dialog. If an LRU or LRM is common to other equipments, or suites within an avionic segment, the inclusive quantity will be accounted for without additional input. In other words, the application will check the inputs of all equipments and suites within the level studied and determine usage. If an analysis has not been conducted, and stored, then commonality will only be assessed at the equipment level from information stored against the ASC Avionics Planning Baseline.

7.2.3 Modularity

The use of line replaceable modules, accurate fault isolation and detection, and commonality are the principal concepts related to two level maintenance. VHSIC-generation microelectronics allow more extensive built-in test for less ambiguous fault detection and fault isolation. The application will analyze LRMs in identical fashion to LRUs, but the user will be cautioned to make sure that the cost of the fault isolation capability required is included.

7.2.4 Multifunctionality

Multifunctionality is the use of the same modules or units of equipment to perform different functions within an avionics suite. For instance, a single electronic module could have the hardware necessary to perform several functions and switching from one function to another would be done with different application software. A case in point is the Integrated Sensor System (ISS) modules being researched under the Pave Pace program. The application will account for multifunctionality by calculating lower unit cost (higher volume), and lower spares cost (fewer types), and perhaps fewer technicians and less test equipment.

7.2.5 COTS

The COTS (Commercial-Off-the-Shelf) program is trying to leverage commercial industry, commercial products, and commercial standards to reduce avionics life cycle cost. COTS products that meet military specifications have become commonplace in markets such as VME CPU boards. The COTS identification will be reflected in the application by the cost quantity curve calculations and reduced development costs.

7.3 Supportability Tradeoffs

Supportability tradeoffs will primarily be made to evaluate the impact of different maintenance concepts on life cycle cost. Included in these concepts will be different repair levels, maintainer cross training, and stock levels. Supportability trade offs will primarily be at the LRU, SRU, or LRM level.

7.3.1 Repair Level Analysis

Repair level analyses will consider the cost of spares, support equipment, shipping and handling, maintenance skill levels, and technical orders based on where the LRU is repaired and compare those costs to the resultant cost if repair is made at a different maintenance level. This analysis is accomplished with separate runs of the program.

7.2.2 Cross Training Analysis

Maintenance training analysis will correlate directly with the repair level analysis. Each level of maintenance training becomes progressively more comprehensive because each level performs more detailed maintenance. Cross training is permissible at a given level when the rate of failure of the LRU repaired at the level does not overload the maintenance personnel or equipments. The primary objective of this analysis will be to look at the overall cost impact of cross training on LCC.

7.3.3 Stock Level Analysis

Stock level analysis will be conducted by comparing spares cost for different hardware implementations and/or changing the probability of no-stock-out at a stockage level.

Conclusion

A methodology for balancing avionics requirements and LCC can be developed by using recent advances in spreadsheet software, object oriented programming and graphical user interfaces. This report has presented a conceptual design for that methodology. It can be implemented with existing Air Force models and databases and the Excel 5 computer program running on Windows 3.1. It can serve Air Force SPOs, Laboratories, and Contractors with a common application interface.

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